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SOME CAUSES OF VARIATION IN THE POLARIZATION OF SKY LIGHT.*

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INTRODUCTION.—Since the discovery of the polarization of sky light by Arago more than a century ago the phenomenon has been studied by many eminent investigators; but, while its general features have been satisfactorily accounted for, certain variations that appear to be connected with atmospheric conditions still remain to be examined and explained. In the present paper the general features of sky polarization will be considered first, together with a brief reference to some of the theories that have been advanced to account for them. There will then follow a more detailed account of certain variations with location and with atmospheric conditions, which have been made the subject of extended observation by the writer.

GENERAL FEATURES.—If we examine with a polariscope the light from a cloudless sky when the sun is on the horizon, we shall find that from 70 to 80 per cent. of the light from the zenith is plane polarized, and that the zenith is the point of maximum polarization. Furthermore, a maximum percentage of polarized light is found in the plane at right angles to the direction of the incident solar rays, although the percentage decreases somewhat

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with angular distance from the zenith. At the time of the equinoxes this plane cuts the horizon at the north and the south points. Along the horizon, therefore, both east and west from these points, the polarization diminishes. It also diminishes as we pass from the zenith towards the east or west; and reaches a minimum, in this case zero, at points from 15° to 25° above the anti-solar point and the sun, and which are called from their discoverers the neutral points of Arago and Babinet, respectively.

Generally speaking, the plane of polarization is the plane containing the sun, the point from which light is observed, and the eye of the observer. For the zenith this coincides with the vertical plane of the incident solar rays; for a point on the horizon it is a horizontal plane; and for an intermediate point, a more or less inclined plane. In the vicinity of the neutral points the plane of polarization is more nearly horizontal than would be the case if the above rule applied, except that directly above them it is vertical. At all points directly below them it is horizontal.

As the sun increases its angular distance above the horizon one continues to find the point of maximum polarization about 90° from the sun and in its vertical. The maximum percentage of polarization is still found in the plane at right angles to the incident solar rays; and one continues to find points of zero polarization above the sun and the anti-solar point, although the distance of the former from the sun gradually diminishes. About the time that Arago's neutral point disappears below the horizon Brewster's neutral point makes its appearance above the horizon underneath the sun. Other neutral points have also been observed at different times.

The principal features of sky polarization are, therefore, a point of maximum polarization about 90° from the sun and in its vertical, a plane of maximum polarization at right angles to the incident solar rays, and points of neutral polarization at about 15° to 25° above and below the sun, and about the same distance above the anti-solar point. The plane of polarization is, in general, the plane containing the sun, the point observed, and the eye of the observer; but this rule does not apply to the region immediately about the neutral points. It will also be useful to remember that the light vibrations occur in a plane which contains the point observed and the eye of the observer, and which is at right angles to the plane of polarization.

EXPLANATION OF SKY POLARIZATION.

EFFECT OF PRIMARY SCATTERING.—Between the years 1871 and 1899 Rayleigh and others showed how a medium made turbid by the presence of particles whose diameters are small in comparison with the wave-length of light would scatter the light, the variation in the intensity of the scattering with direction being expressed by $1 + cos^2\beta$, where β is the angular departure from the line of incidence. According to this law the scattering would be twice as intense in the line of incidence as at 90° from it. Furthermore, it was shown that light scattered from an unpolarized beam would be completely polarized in a plane at right angles to the incident beam. That is to say at right angles to incidence all the light vibrations would take place in this one plane. In the direction of the sun and of the anti-solar point, respectively, the light would be unpolarized. Between these points and the plane of maximum polarization the fraction of the light polarized would be expressed by $\frac{sin^2\beta}{1+cos^2\beta}$, or the percentage of the light polarized would vary between 0 and 100.

EFFECT OF SECONDARY SCATTERING.—In 1888 Soret[1] showed that if the small diffusing particles were distributed uniformly throughout a hemisphere the effect of secondary scattering would be identical to the effect produced by a beam of natural light coming directly from the sun, plus the action of a beam of much less intensity contained and polarized in a plane perpendicular to the direction of the sun. The vibrations in this beam are therefore at right angles to the vibrations in the primary scattered light, and this beam is said to be negatively polarized in distinction from the prevailing, or positive polarization. The effect of this negatively polarized beam will be everywhere to neutralize a part of the positive polarization, thus giving only partial instead of total polarization 90° from the sun. In the directions toward and from the sun, however, the light would still be unpolarized.

But the diffusing particles, instead of being distributed uniformly throughout a hemisphere, are actually contained in a relatively small segment of a sphere, and there are many more particles, both of gas and of foreign substances, in the lower layers than in the upper. As an approximation to the actual distribution, Soret supposed a horizontal ring of diffusing particles

to superpose its effect upon that of the hemisphere. In the light scattered by this ring horizontal polarization would predominate; and in the direction of the sun and of the anti-solar point the superposition of this component upon the components due to primary scattering and the secondary scattering by the assumed hemisphere, would result in horizontally polarized light. As we proceed towards the zenith, however, we soon reach points where the vertically polarized light just neutralizes the horizontally polarized, giving us the so-called neutral points.

DIFFUSION BY LARGE PARTICLES.—Wiener[2] has shown that the presence of water drops would have little effect upon the polarization 90° from the sun; that ice crystals would appreciably diminish the polarization in that direction; and that, within limits, the presence of any particles whose diameters are large in comparison with the wave-length of light would greatly increase the sky illumination and the proportion of natural light in the vicinity of the sun.

REFLECTION FROM THE SURFACE OF THE EARTH.—My own observations, confirming those made by others, show that when snow covers the ground the percentage of sky polarization at the point of maximum may be diminished from 70 per cent. to 50 per cent., which corresponds to an increase in the ratio of the unpolarized to the polarized light of from 0.43 to 1.00. It is therefore evident that reflection from the surface of the earth increases the proportion of natural light. Reflection from large particles suspended in the atmosphere would also produce this same effect.

CAUSES OF VARIATION IN SKY POLARIZATION.—It therefore appears that an increase in the number of the diffusing particles, large or small, in the lower layers of the atmosphere, and, likewise, that increased reflection from the surface of the earth, must produce a diminution in the positive polarization of sky light, and at the same time increase the distance of the neutral points of Arago and Babinet from the anti-solar point and the sun, respectively.

PERIODIC VARIATIONS.

For many years Jensen[3] has measured the percentage of polarization at the zenith at different hours of the day. After correcting his readings for varying zenith distance of the sun, he finds that the minimum polarization occurs at about the time

of maximum temperature, which is also the time of maximum convection.

Rubenson [4] found the polarization at the point of maximum to be less in summer than in winter, a fact that may also be partly attributed to convection.

Busch [5] has found the distances of the neutral points of Arago and Babinet from the anti-solar point and the sun, respectively, to vary greatly from year to year,—in the case of the latter from an average of 15.4° in 1890 to an average of 30.8° in 1903. Reference may also be made to my own observations,[6] which show that the polarization at the point of maximum in the year 1903 averaged 10 per cent. less than the average for the years 1903 to 1910, inclusive. The year 1903 followed violent volcanic eruptions in the West Indies and Central America. Although this was not a year of maximum sun spots, Jensen [7] points out an apparent connection between the years with a maximum of sun spots and the years when the neutral points are at a maximum distance from the sun and the anti-solar point.

NON-PERIODIC VARIATIONS.

EFFECT OF WATER VAPOR.—Some observations by Crova and Houdaille [8] in 1888 indicate a connection between atmospheric transmission of solar radiation and sky polarization. During the past five years I have made a great many observations that clearly show such a connection. They also show a relation between sky polarization and local conditions, such as character of the soil, convection, etc. In order that these various relations may be more easily understood, the observations are summarized in Table I, where P_2 indicates the percentage of polarization of sky light at the point of maximum, e the vapor pressure, and Q_2 the intensity of solar radiation on a surface normal to the sun's rays and at mean solar distance, expressed in gram-calories per minute per square centimetre. P_2, e and Q_2 were all three measured when the sun was 60° from the zenith. The significance of Q'_2 is given below.

The Washington observations cover the period from December, 1905, to May, 1910. Observations at other stations, including some at Madison, Wis., on the position of the neutral points, and which are given in Table III, were obtained in connection with field work during the summer and fall of 1910. All the data were obtained when the sky was practically cloudless.

TABLE I.—SUMMARY OF SOLAR RADIATION AND SKY POLARIZATION OBSERVATIONS WITH THE SUN 60° FROM THE ZENITH.

No. of half-day series of observations	P_2	e	Q_2	Q'_2
	Per cent.	Mm.	Calories	Calories
WASHINGTON, D. C.				
GROUP 1				
10	70.8	3.54	1.329	1.302
GROUP 2				
10	68.2	1.93	1.314	1.269
9	66.2	2.76	1.259	1.223
15	62.4	2.39	1.238	1.198
4	57.8	2.89	1.183	1.149
7	51.9	3.95	1.057	1.034
Averages	61.3	2.78	1.210	1.175
GROUP 3				
8	67.7	4.47	1.271	1.254
7	65.8	6.66	1.255	1.262
13	63.1	6.07	1.223	1.224
5	57.4	8.32	1.077	1.103
7	53.2	9.69	1.002	1.043
Averages	61.4	7.04	1.166	1.177
GROUP 4				
2	43.0	7.63	0.884	0.902
SANTA FÉ, NEW MEX.				
Sept. 20, A.M.	61.0	6.50	1.282	1.286
Sept. 19, A.M.	70.8	8.48	1.360	1.382
13, P.M.	70.0	7.87	1.390	1.407
18, A.M.	68.7	8.81	1.343	1.368
8, P.M.	67.8	8.48	1.334	1.356
9, A.M.	66.8	8.48	1.319	1.341
Averages	68.8	8.42	1.349	1.371
FLAGSTAFF, ARIZ.				
Dates				
Sept. 25, A.M.	70.6	5.16	1.420	1.412
27, A.M.	70.1	4.17	1.360	1.344
28, A.M.	69.8	3.40	1.440	1.417
30, P.M.	69.3	2.49	1.452	1.420
26, A.M.	68.1	4.95	1.397	1.388
28, P.M.	68.1	2.62	1.417	1.387
26, P.M.	66.5	3.99	1.359	1.341
Averages	68.9	3.83	1.406	1.387
PHOENIX, ARIZ.				
Oct. 5, A.M.	63.2	7.04	1.228	1.239
3, A.M.	62.8	8.13	1.291	1.314
5, P.M.	62.7	8.81	1.268	1.299
3, P.M.	62.0	8.81	1.319	1.350
7, A.M.	60.7	5.16	1.292	1.283
7, P.M.	59.6	4.17	1.337	1.317
6, P.M.	59.4	5.79	1.240	1.238
8, A.M.	59.4	4.37	1.274	1.256
6, A.M.	58.6	8.18	1.239	1.263
Averages	60.9	6.72	1.276	1.284

The data for Washington have been arranged in four groups in such a way that the averages for groups 2 and 3 give nearly equal values for P_2, but values of e differing by 4.26 mm. The corresponding difference in the values of Q_2 is 0.044, indicating that an increase of 1 mm. in the value of e diminishes the value of Q_2 by 0.010. This is very closely in accord with the empirical equation of Abbot and Fowle,[9] namely, $F = 5.1 + 0.12\ E_0 m$, where F indicates the depetion of solar radiation intensity due to water vapor band absorption in the solar spectrum expressed as a percentage of the value of the solar constant. $E_0 = 2.3\ e$ is the vapor content of the atmosphere expressed in millimetres of depth of water, and m is the secant of the sun's zenith distance. When $m = 2$, a change of 1 mm. in e will produce a change of about 0.55 in F, which is equivalent to a change in the intensity of solar radiation of about 0.011 calories, or practically the same as found from the data in Table I.

We may therefore employ the equation

$$Q'_2 = Q_2 - 0.011(e' - e)$$

to adjust the values of Q_2 obtained with various values of e to values Q'_2, corresponding to any desired uniform value of $e = e'$. In Table I they have been adjusted to a value of $e' = 6.0$ mm. The resulting values of Q'_2 show very clearly that a relation exists between Q'_2 and P_2, but do not indicate a direct relation between the latter and e.

Similarly, the averages for Santa Fe, N. Mex., and Flagstaff, Ariz., if we omit the data for Santa Fe on September 20, give nearly equal values for P_2, but values of e differing by 4.59, and values of Q_2 differing by 0.057, indicating a diminution of 0.012 in Q_2 for an increase of 1.0 mm. in e. Santa Fe is about 7000 feet and Flagstaff about 6900 feet above sea level. At this elevation the investigations of Abbot and Fowle [10] indicate that an increase of 1.0 mm. in e should cause a diminution of only 0.009 in Q_2. However, after employing this latter value to obtain Q'_2 corresponding to $e' = 6.0$ mm., the data indicates that with a transparency of the atmosphere at these two stations such that their average values of Q'_2 differ by only about one per cent., the averages of sky polarization are in accord. Here again the effect of e upon the value of P_2 is not apparent.

After adjusting the values of Q_2 obtained at Phoenix, Ariz., to values of Q'_2 corresponding to $e' = 6.0$ mm., we may bring

together in Table II the average values for Flagstaff, Santa Fe, and Phoenix, and the averages for the best observations at Washington, which latter have been obtained from the data for group 1, the first ten series of group 2, and the first eight series of group 3. From this table it is evident that with a given transparency of the atmosphere after allowance has been made for band absorption by aqueous vapor, the percentage of polarization of sky light with the sun 60° from the zenith is greatest at Washington and least at Phoenix.

In Table III are given observed distances of the neutral points of Arago and Babinet from the anti-solar point and the sun, respectively, and the highest polarization that has been observed with the sun on the horizon. At Washington no observations have been made on the position of Babinet's neutral point, and at

TABLE II.—AVERAGES OF SOLAR RADIATION AND SKY POLARIZATION WITH THE SUN 60° FROM THE ZENITH.

Station	Elevation	P_3	ϵ	Q_3	Q'_3
	Feet	Per cent.	Mm.	Calories	Calories
Flagstaff	6900	68.9	3.83	1.406	1.387
Santa Fé	7000	68.8	8.42	1.349	1.371
Phoenix	1100	60.9	6.72	1.276	1.284
Washington	100	69.0	3.23	1.307	1.276

Madison no measurements were made of the polarization at the point of maximum. The data indicate that with the sun on the horizon the positively polarized light, which results principally from the primary scattering by small particles, is relatively the weakest at Washington and Madison, and strongest at Flagstaff and Santa Fé.

Comparing the data of Tables II and III, it is seen that the difference in sky polarization with the sun on the horizon and at 30° above is least at Washington and greatest at Phoenix.

If we study the local conditions that exert a modifying influence upon sky polarization, it must be noted that Washington and Madison are in regions of dense vegetation both with respect to the forested areas and the open country. Phoenix, Ariz., is in a treeless valley; the soil is light in color and extremely fine in texture, and at times the dust arising from it covers the surface like a fog. About Santa Fé the country is generally covered with

a scattered growth of stunted trees, while Flagstaff is in the midst of a forested area, although the growth is much less dense than is the case in the Eastern States. These two latter stations are near the foot of valleys, at the heads of which are mountains over 12,000 feet high. There is strong air drainage down these valleys at night, and in consequence the atmosphere at sunrise is remarkably clear. Soon after sunrise the valleys become hot, and there is a reversal of wind direction, which brings in more or less dust from the plains below. At Santa Fé the pyrheliometer readings at this time sometimes showed a falling off in radiation intensity of as much as 8 per cent. even before the wind at the surface had changed its direction. This was accompanied by decreased polarization of sky light at the point of

TABLE III.—SKY POLARIZATION OBSERVATIONS WITH THE SUN ON THE HORIZON.

Station	Distance of Arago's neutral point from the anti-solar point			Distance of Babinet's neutral point from the sun			Maximum polarization in zenith	Period covered by the observations
	Max.	Min.	Mean.	Max.	Min.	Mean.	Per cent.	
	°	°	°	°	°	°		
Washington, D. C.	21.2	16.4	19.1	....	....	....	74.9	Jan. 8–May 19, 1910
Madison, Wis.....	21.7	18.0	19.6	18.8	17.6	18.0	....	July 25–Aug. 4, 1910
Phoenix, Ariz.....	19.5	18.2	18.8	19.1	16.2	17.7	75.4	Oct. 3–Oct. 8, 1910
Flagstaff, Ariz.....	21.6	16.1	17.9	18.8	14.4	16.0	78.9	Sept. 25–Sept. 30, 1910
Santa Fé., N. M...	18.5	16.1	17.2	16.2	14.7	15.5	78.2	Sept. 7–Sept. 20, 1910

maximum, and was usually followed by the formation of cumulus clouds. At Flagstaff the effect of the reversal in wind direction on the pyrheliometer readings and on the polarization was less marked, and there was less tendency to form clouds; but both solar radiation intensity and sky polarization showed a slight falling off in the afternoon, which was undoubtedly due to the increased scattering of light in the lower atmosphere on account of the dust introduced by convection.

At Phoenix the radiation was more intense during the afternoon than during the morning hours, without a corresponding increase in sky polarization. This may have been due to the effect of smoke from the city, which diminished noticeably in density as the day advanced, perhaps on account of a decided diurnal variation in wind direction. In this way the atmospheric transmission in the direction of the sun might be increased,

without noticeably affecting either the secondary scattering or the reflection from lower surfaces in a direction 90° from the sun. The distance of Babinet's point from the sun was slightly greater at sunset than at sunrise at both Phoenix and Flagstaff. The increased dustiness of the atmosphere due to convection appears, therefore, to have slightly decreased the sky polarization during the afternoon as compared with the forenoon hours at the three stations above named.

It is not believed that the great diurnal variation in sky polarization observed at Phoenix as compared with that at Flagstaff and Santa Fé, and especially as compared with that at Washington, can be attributed to convection, since we do not find a corresponding diminution in atmospheric transmissibility.

TABLE IV.—SKY POLARIZATION WITH DIFFERENT REFLECTING SURFACES.

Station	Date	Sky polarization		Remarks
		Noon	Sun on horizon	
		Per cent.	Per cent.	
Santa Fé, N. Mex.....	Sept. 8, 1910	68.2	77.6	Clear sky.
Santa Fé, N. Mex.....	Sept. 11, 1910	56.2	....	Sky $\frac{1}{10}$ covered with cumulus clouds at noon.
Phoenix, Ariz.....	Oct. 7, 1910	59.1	73.0	Clear sky.
Washington, D. C.....	Dec. 23, 1908	50.6	66.6	Clear sky. Snow on ground.
Washington, D. C.....	Dec. 1, 1909	71.0	74.1	Clear sky. No snow.

Perhaps analogous conditions exist at Santa Fé when clouds commence to form, and at Washington when the ground is covered with snow. Polarization data for these several conditions are given in Table IV.

There was little difference in solar radiation intensities at Santa Fé on September 8 and 11, 1910. At Washington the radiation was more intense on December 23, 1908, than on December 1, 1909.

It seems rational to attribute the low percentage of sky polarization at noon at Phoenix to causes similar to those that produced like effects at Santa Fé and Washington, namely, reflection of light to the sky from low-lying surfaces. In the case of Santa Fé these were the surfaces of cumulus clouds; at Washington the light was reflected upwards from a snow surface, and at Phoenix from the light colored surface of the ground and the dust layer just above it.

In comparing sky polarization observations at different stations it is therefore necessary to take into account the relative intensities of reflection from the surface.

It now remains to account for the apparent relation between Q'_2 and P_2 indicated by the data for Washington in Table I, and of which we find little trace in the data for other stations, except possibly at Santa Fé. In other words, when the solar radiation intensity decreases from 1.302 to 0.902, why does the sky polarization diminish from 70.8 to 43.0, as shown in the averages of groups 1 and 4 in Table I?

From my original records it is found that of the ten series of observations included in group 1, seven occurred in November,

TABLE V.—DAYS WITH LOW VALUES OF P_2 AND Q'_2.

Date	P_2	θ	Q_2	Q'_2	Wind, direction	Remarks
Oct. 10, 1907, P.M..	52.9	8.18	0.992	1.016	SE.	Rain on Oct. 11.
June 8, 1908, P.M..	52.2	12.68	1.016	1.089	SE.	Rain on June 9.
May 1, 1908, A.M..	52.1	3.63	1.113	1.087	NW.	Rain on May 2.
June 27, 1908, A.M..	52.0	13.61	0.982	1.066	SW.	Rain, P.M., June 27.
Apr. 29, 1908, P.M..	51.9	4.75	1.049	1.035	S.	Rain on April 30.
Apr. 17, 1906, A.M..	51.6	4.57	1.036	1.020	NW.	Followed period of heavy rain.
Apr. 17, 1908, A.M..	51.4	3.81	0.994	0.970	SE.	Lunar halo, 1 A.M., 18th; Rain, 18th.
Apr. 17, 1906, P.M..	51.0	4.44	1.017	1.000	NW.	Followed period of heavy rain.
Apr. 25, 1907, A.M..	43.4	6.76	0.931	0.939	S.	Lunar halo, P.M., 25th, Rain, 26th.
May 18, 1906, P.M..	42.5	8.50	0.838	0.866	NW.	Excessively hot.

1906, in the southeastern quadrant of decided high barometric areas, and the remaining three occurred in September, November, and December, 1909.

The two series in group 4 and the eight series in groups 2 and 3 having the lowest values of P_2 and Q'_2 were all obtained in the months of April, May, and June, except one, which was obtained in October. Data relative to these ten series is given in Table V, from which it is seen that lunar halos were observed on the nights following two of them, and that seven were followed by rain before midnight of the succeeding day.

On none of these days was there marked dustiness or smokiness in the lower layers of the atmosphere, and there was almost a complete absence of clouds, although on some days it was noted that the sky had a streaked appearance. It therefore appears that we here have to do with optical haze, or reflection from non-homogeneous layers or currents of air. According to

Hann,[11] its occurrence under certain conditions is indicative of the approach of fine weather, while under certain other conditions it is evidently the forerunner of nucleation and rain.

CONCLUSIONS.

From the data here presented it appears that while the polarization of sky light is greatly modified by reflection from the surface of the earth it is intimately connected with meteorological processes and conditions.

Decreased polarization may be produced by mechanical haze, due to the presence of large particles of any description in the atmosphere, or by optical haze, due to a lack of homogeneity in the atmospheric layers. While this latter condition is not of itself a sufficient criterion on which to base a weather forecast, in connection with other data it should be of assistance in determining the extent to which upper air conditions are disturbed. It is a question, however, whether pyrheliometric readings would not be more useful for this purpose, since these latter are only affected by the conditions along the path of the incident solar rays.

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THE CONSERVATION OF IRON.*

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THE history of the human race might be written in the history of iron. From far back of the early times when man learned to chronicle his triumphs and achievements on tablets of stone, there come down to us the dim traditions of the winning from iron bearing stones of the wonderful metal which was destined to be the greatest instrument of his struggles and of his uplift throughout the ages. Indeed the tablets of stone on which early man recorded his deeds and laws stand as proofs that the development of cutting tools and weapons preceded the art of writing.

Whether as sword, ploughshare, pen, compass needle, or machine, this wonderful and indispensable metal has led men along the paths of conquest, empire and evolution. The historian [1] may well conclude that the saying of Bishop Berkely, "Westward the course of empire takes its way," has received a new interpretation, for the iron industry, the source and sign of material power, which had its beginnings in Asia, the cradle of the race, passed along the Mediterranean into western Europe, crossed the Atlantic Ocean and now finds a home in the valleys of the Rockies and by the Golden Gate to the Pacific. It has made the circuit of the world, and now in the face of an awakened and stirring Orient, thoughtful men are asking if perchance it is preparing for a second cycle.

It is the object of this paper to point out the importance of the conservation of iron in so far as practical methods present themselves for accomplishing results. We may, however, by way of introduction permit ourselves a brief survey of historical data. Herodotus tells us of the early use of iron by the inhabitants of Asia, the Egyptians and other early civilizations. The early traditional writings of the Hebrews teem with allusions to the development of artificers of iron, from Tubal Cain, the first blacksmith of record, to Nebuchadnezzar, King of Babylon, who

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[1] Swank, Iron in All Ages.

in a noted inscription records: "With pillars and beams plated with copper and strengthened with iron, I built up its gates." The prophet Daniel says: "Iron breaketh in pieces and subdueth all things," and "Thou shalt break them with a rod of iron," is the adjuration of the Psalmist.

The earliest steel workers of record were the Chalybians who lived on the southeastern shores of the Black Sea, although other ancient eastern peoples had been almost equally renowned in history and tradition. In the British Museum there are examples of iron and steel tools which are probably more than 3000 years old. The ancient swords of Damascus are famed in song and story and we are told were of such keenness and temper that they could cleave a floss of silk floating in the air or sever a massive iron helm, with equal facility.

Far back, however, of authenticated historical data, the ancient Chinese peoples developed the metallurgy of iron to an art, and this metal is said to have been mentioned in Chinese writings more than 3000 years before Christ. In later times, Pliny the elder, who lived in the first century of our era, testifies as to the excellence of the iron made by the Chinese.

The beautiful iron monument of Kutab Minar near Delhi, India, is of great antiquity, although its exact period is in doubt. Randolph, an American who visited Delhi in 1874, records that he attempted to secure a few grains from the base of the monument for analysis but that it completely dulled two cold chisels worked by his servant without producing any marks on the base of the pillar.[2] Although this extraordinary statement taxes our credulity, there can be no doubt that the old, hand wrought, charcoal smelted irons were of a grade of excellence that modern steel makers find it difficult to attain. It is also noteworthy here that the iron column of Delhi has resisted the corrosive influence of the atmosphere for many centuries, with no protective coating beyond that which nature may herself have provided. In regard to density, homogeneity, temperability and resistance to corrosion, the fame of the older metals has come down to us, and in truth there is a mass of testimony to prove that inferior qualities began first to seriously show themselves contemporaneously with the introduction of the great modern pneumatic processes used in manufacturing both iron and steel.

[2] Swank, Iron in All Ages, p. 9.

We live, however, in a practical age and it is essential that we should consider our great industrial problems from a practical view-point. No sensible persons would venture to propose a return to the old hand worked methods of manufacture, for modern conditions could not support such an industry. In the old Wootz and Catalan processes, very pure magnetite and hematite ores, first pulverized and thoroughly lixiviated and washed were used. They were then little by little puddled out by burning with charcoal in a pit or oven and subsequently beaten and forged by patient industry to the desired form. It seems to be a law of Nature that her materials should respond to the manipulations of the hands of man and acquire properties that machinery cannot give. As an example of this, we have only to remember the everlasting qualities of the hand worked lacquers and enamels of the Orient and compare them with the machine and brush laid coatings of our own industrial processes. The poet Virgil who lived before Christ has drawn a picture which brings vividly to mind the intense manual labor involved in early metallurgical operations:

> [8] As when the Cyclops, at th' almighty nod,
> New thunder hasten for their angry god,
> Subdued in fire the stubborn metal lies:
> One brawny smith the puffing bellows plies,
> And draws and blows reciprocating air:
> Others to quench the hissing mass prepare:
> With lifted arms they order every blow,
> And chime their sounding hammers in a row:
> With labored anvils Etna groans below.
> Strongly they strike; huge flakes of flames expire:
> With tongs they turn the steel and vex it in the fire.

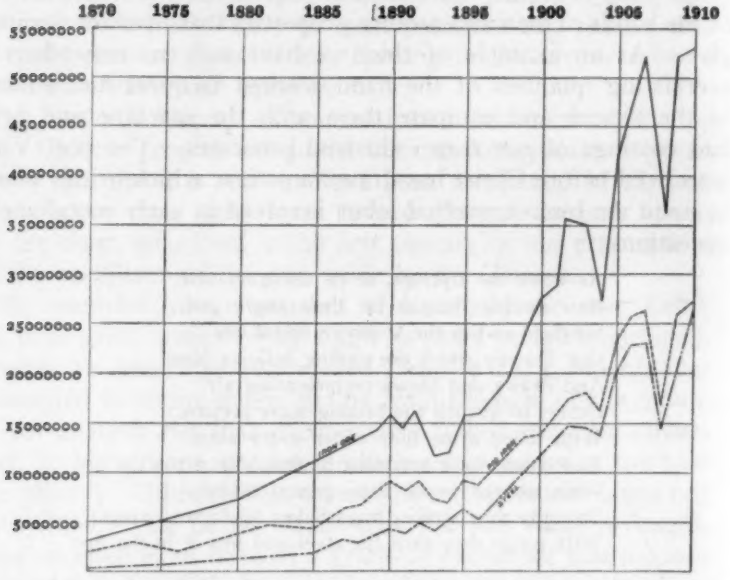
The Nineteenth Century ushered in the age of steam and from this point the history of iron exerts an even more potent influence than before over the development of the human race. The names of Watt, Stevenson, Bessemer and Siemens will never require bronze monuments to perpetuate them, for as long as iron is made or moves they will be remembered.

It was significant that the steam-engine, the locomotive and the great pneumatic process for steel making should have appeared at almost the same moment, as though indeed an over-

[8] Quoted from Swank, *loc. cit.*

shadowing Providence had a deep laid design for the industrial future of the race. It is a curious thought too that experience and tradition teaches us that all the gifts of Nature or Providence have penalties attached. The Golden Age told this truth in song and story, as in the Hebrew tradition of the banishment from Eden, or in the Homeric legends of the Greeks. And now, in turn, the Iron Age exacts its penalties and the gigantic industrialism of modern man threatens the future with its penalties.

FIG. 1.



Curve showing the production of iron ore, pig-iron, and steel in the United States, 1870 to 1910, in long tons.

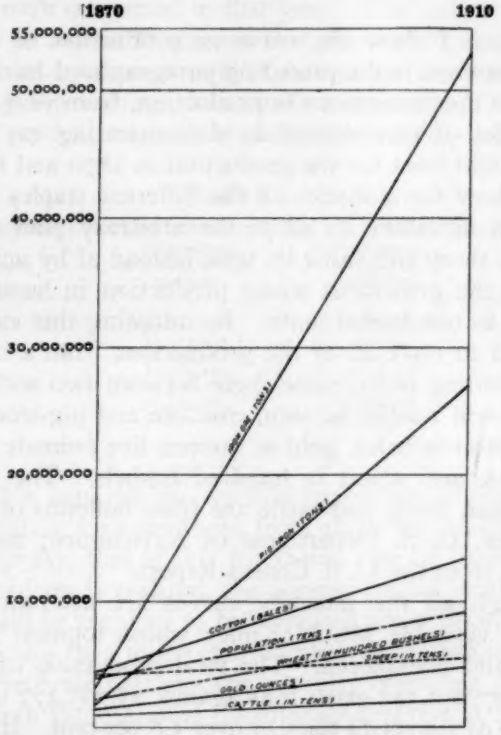
Probably no one who has not made a special study of the conservation of iron has a fair conception of the problems which the question presents.

I have chosen for my theme to-day the presentation of this subject, along a line which I venture to hope will bring out the relation of iron conservation problems to the general subject of intensity of growth in civilization. I have chosen to begin my analysis from the year 1870, because from this date on there

begins the steep rise in what for want of a better characterization I shall call the intensity curves of civilization.

In order to simplify my purpose and because the statistics are more readily available, I have confined myself to the data which applies only to the United States, but these may be taken as fairly indicative of the world's curves.

FIG. 2.



Intensity curves on staple products in the U.S. from 1870 to 1910.

As it is impossible to include in a tabular or graphic representation all the staples, the production and consumption of which may be taken as the measure of intensity, I have made an arbitrary selection in order to illustrate my point. I start with the premise that the necessities and the energies of human life can be very simply analyzed. Food and clothing, the prime human

necessities, can for our purpose be represented by wheat and cattle,[4] sheep and cotton, and the source and sign of material energy by iron. Gold, the measure of value and medium of exchange, is included, for reasons which are sufficiently obvious, and finally the growth in population is also shown.

I first present in Fig. 1 the curve showing the growth in the production of iron ore, pig-iron and steel, the data having been compiled from the figures furnished by the U. S. Geological Survey.

In Fig. 2 I show the curve in production of the various staples mentioned in the preceding paragraph. I have not in this table shown the fluctuations in production, from year to year, but for the sake of convenience in demonstrating my point have drawn straight lines for the production in 1870 and in 1910. In order to show the statistics of the different staples graphically, it has been necessary to adopt the arbitrary plan of counting population, sheep and cattle by tens, instead of by units, and also to express the growth in wheat production in hundred bushels instead of in one bushel units. By adopting this expedient, we are enabled to start all of the productions from a more or less common starting point, somewhere between two and six million units. As will readily be seen, iron ore and pig-iron are shown in tons, cotton in bales, gold in ounces, live animals and population in tens, and wheat in hundred bushels. The statistics on cotton, wheat, sheep and cattle are from bulletins of the Bureau of Statistics, U. S. Department of Agriculture; the figures on population from the U. S. Census Report.

Although all the intensity curves are ascending, the iron curve is a veritable Mt. McKinley whose topmost peak is still unknown and unexplored. The total production of pig-iron in 1910 was 27,290,545 gross tons against 25,795,471 tons in 1909, an increase of 1,503,074 tons, or over 5.8 per cent. It is, however, when contrasted with the increase in population that the iron statistics come out most strongly. The per capita production of pig-iron in the United States has increased more than 1000 per cent. since 1850. If the rate that was recorded in the last decade is in any degree approximated in the present, the per capita production will exceed one-half ton before 1920 is reached.

[4] The cattle statistics used refer only to milch cattle.

Table I gives the total and per capita production of the last seven census years:

A Spanish statistician [5] has recently published an interesting review of the question of the iron ore supplies of the world. To bring home the far-reaching importance of the matter, he draws attention to the fact that the annual production of iron has risen from 5 million tons at the middle of the Nineteenth Century to nearly 61 million tons in 1909, and for this about 140 million tons of ore were consumed in that year. This author points out that there is no reason to suppose that the world's output of iron has reached its maximum point but that on the contrary it is likely during the coming decades that the rate of the annual increase in production will be fully maintained and probably

TABLE I.

Calendar years	Population of United States, number	Production of pig-iron, gross tons	Per capita production, pounds
1850	23,191,876	563,755	61.6
1860	31,433,321	821,223	63.6
1870	38,558,371	1,665,179	105.6
1880	50,189,209	3,835,191	178.0
1890	62,979,766	9,202,703	318.1
1900	76,303,387	13,789,242	386.8
1910	91,972,266	27,298,545	664.7

surpassed. He assumes the world's production of iron in 1920 will be 93 million tons produced from about 217 million tons of ore, that is to say, that if this forecasted rate of increase in the production of iron is realized, the present annual world's output of iron ore will be required to be increased about 88 million tons.

We must now turn to the consideration of the resources which must stand the drain that modern intensity is putting upon them. At the Eleventh International Geological Congress at Stockholm, which met last year, there was presented a lengthy report [6] upon the amount and distribution of the world's supply of iron ore. Practically every country where iron ore is worked is represented. The total known supply of iron ore of the world is estimated on Table II.

[5] J. de Lazurtegui, Ensayo sobre la cuestión de los Minerales de Hierro Ayer, Hoy y Mañana, Bilboa, 1910, pp. 1–145.

[6] Iron Ore Resources of the World, Stockholm, 1910.

The *Journal of the Iron and Steel Institute* comments upon Table II as follows: To what extent the future of iron will become dependent upon low grade ores is shown in this report. The actual reserves of rich ores containing 60 per cent. of iron are estimated at 1300 million tons, and the potential reserves at 687 million tons. Four-fifths of the known and recorded rich ores are contained in the deposits of northern Sweden.

As has already been stated, it is the object of this paper to consider the conservation of iron principally from the stand-point of our own immediate problem in the United States. The statistics already given show very clearly that the annual production of iron ore may very possibly reach the 100 million ton mark if the present general tendency towards increase is maintained for a few more decades. If we could assume that this figure would not be surpassed but would become an upper limiting value, the

TABLE II.

	Actual reserves		Potential reserves	
	Ore, metric tons (millions)	Iron, metric tons (millions)	Ore, metric tons (millions)	Iron, metric tons (millions)
Europe	12,032	4,733	41,029	12,085
America	9,855	5,154	81,822	40,731
Asia	260	156	457	283
Australia	136	74	69	37
Africa	125	75	many thousands	many thousands
Totals	22,408	10,192	123,377	53,136

situation would hold no menace for the western hemisphere for many generations yet to come. The actual and potential ore reserves of America given in Table II are sufficient even at this rate to last nearly one thousand years, and we may as well admit that we need feel little responsibility in regard to our remote descendants who may exist in ten centuries from the present era. With respect to the United States and the situation which children now born will have to cope with, we are, however, vitally concerned. Mr. John Birkinbine,[1] in an interesting article on the "Production and Resources of the Lake Iron Region," has published some valuable figures. He gives the total contribution to

[1] The Mining World, vol. xxxiii, No. 10, p. 417.

the iron ore supply of the United States made to the close of 1909 by each of the ranges included in the Lake Superior district, which produces about 80 per cent. of all iron ore mined in the United States.

Mesabi	195,703,424
Marquette	91,903,991
Menominee	71,313,115
Gogebic	60,820,503
Vermillion	29,125,385
Total	448,966,418

Birkinbine also states that a report was issued in 1908 by the Minnesota Tax Commission, which claimed that a conservative estimate of the available iron ore lands in the lake iron region showed a reserve of 1,192,500,000 tons of iron ore, the bulk of which is on the Mesabi range.

Dr. C. W. Hayes, the well-known statistical expert of the U. S. Geological Survey, has given an extremely interesting review of the iron situation.[8] He says in part: "If the average rate of increase by decades should be continued, it would require the production in the next three decades of 6,088,000,000 tons of ore. But the ore supply now available in the United States is estimated at 4,788,000,000 tons, which is only 78 per cent. of the amount needed on this assumption. It is evident, therefore, that the present average rate of increase in production of high grade ores cannot continue even for the next thirty years, and that before 1940 the production must already have reached a maximum and begun to decline, and a very large use must be made of low grade ores not now classed as available. The second condition, with its consequently greatly increased cost of iron, is the only thing which can prevent a decline in the iron industry, measured by the amount of pig-iron produced within the next thirty years, unless there is in the meantime very greatly increased importation of foreign ores."

Dr. Hayes, however, further points out what I wish to emphasize here, that it is impossible to accurately predict the date of exhaustion of the iron ore supplies and that any attempt to do so is wholly unprofitable and unwarranted. It will readily be

[8] Mineral Resources of the United States, 1908, U. S. Geological Survey.

seen that there are too many factors which enter into this problem, both from the stand-point of political economy and technical development, the tendency of which is not always determinable. It is, however, safe to say that an analysis such as has been attempted in this paper should do good by stimulating more careful study by the public generally of an interesting situation which undoubtedly exists. The normal intensity flow as shown in Fig. 2, which in a sense measures the growth of humanity and civilization in the United States, may be considered to be that which is bounded by the lines for cattle and cotton. The intensity curves for iron, as can clearly be seen at a glance, are out of all proportion to the other staples which in their aggregate may be taken as a measure of modern development.

Another interesting feature of the iron conservation problem which is frequently overlooked is the relation between iron and coal. It is estimated that every ton of iron ore produced requires about four tons of coal or its equivalent in fixed carbon to convert the ore into merchantable iron and steel. An ultimate annual consumption of 400 million tons of coal per year for this purpose alone is therefore to be anticipated in the not distant future.

In presenting this paper on the conservation of iron, there has been no intention on the part of the author to approach the subject in a pessimistic or malthusian attitude of mind. The world is working out other problems and it will undoubtedly work out this one. The exhibition and application of energy or even the very existence of the human race without iron is unthinkable from the stand-point of our present knowledge. In the main, the problem is one for the political economist and as this phase of the subject carries us onto ground somewhat unfamiliar to the writer, we will pass to the technical side of the discussion. It would seem, however, that free entry of raw materials into this country is sure to be demanded in the near future, whether some of us like it or not. The high grade ores of northern Sweden, of Asia, of South America, and of British North America will be as necessary to our industry as to that of our national competitors. From this point of view perhaps the wise statesmanship which is seeking to bring about reciprocity with our American neighbors has not been as highly appreciated as it deserves, by large numbers of our people.

From the technical stand-point, the conservation of iron pre-

sents interesting problems which we will now proceed to briefly consider. The tendency of iron to oxidize or rust is inherent in its nature. The rusting of iron is essentially a process of slow combustion which is annually burning up an untold and unknown quantity of this precious metal. Forest fires in one great blazing conflagration can destroy hundreds of millions of dollars worth of valuable timber. Kindly Nature assisted by the arts of man can cause the forest to grow again, but no partnership between industry and Nature will ever again reclaim the iron that has fallen away to rust. If it were possible to obtain statistics capable of showing even approximately the quantity of iron which annually burns to rust, they would probably astonish us. Unfortunately, such statistics will never be available. It is not even possible to obtain reliable data in regard to the quantity of iron which goes to the scrap pile each year. It is, of course, well known that a very considerable quantity of selected scrap goes back to the furnace to be used again, and in even the best open-hearth steel practice about 50 per cent. of the total charge consists of high grade scrap. In addition to this, low grade scrap is used for common castings and for other purposes, but in spite of all this there must be a vast quantity of junk which is destined never again to become serviceable to man.

I quote from an interesting article in a recent issue of one of the great New York newspapers: "An enormous quantity of new iron is continually being mined and manufactured and apparently added to the world's stock of material, and yet the available pile of usable metal does not rapidly increase. The fact is that only a small portion becomes permanently available stock. Not more than a quarter of the world's iron is used a second time, and not more than a quarter of this goes through a second scrapping. Where does it all go? We get many suggestions as to where and how the iron is dissipated, or, as we say, consumed; this consumption being as complete and final for the portions considered as the consumption of coal or wheat. In the processes of manufacture, in the melting and forging, there is burning of metal, and in all the cutting operations of the shops there is waste, only the larger chips representing recoverable material. The dissipation by wear is more rapid than one would think. Dr. Soper, in a recent valuable paper before the Boston Society of Civil Engineers, says that he found that, by actual

record of material replaced, there was produced in the New York Subway, from the brake shoes alone, one ton of iron-dust per month per mile. The waste of wheels and rails was not so easily ascertainable, but it is to be added to this.

"The same rate of iron-dust production was estimated for the elevated railroads, while the same process was also in operation on the surface roads and, more slowly, of course, with all running vehicles. On the big railroads account is kept of the weight of the cars in use. A large number of steel hopper cars showed an average loss of weight of 702 pounds the first year, with continuous losses, not always at the same rate, for subsequent years. Some of this loss, of course, was due to wear and some to rust. The rusting of iron goes on always, and in some extensive lines of manufacture, as for instance wire fences, and the various iron articles in domestic service, the entire output ultimately goes to rust. Old iron lies around everywhere, some of it too small and much of it too insignificant to be individually noticed, slowly disintegrating, some of it going into the air, some into water, and some into the soil,and through these media into untraceable combination and activities. Dr. Soper, in the paper referred to above, says that he has never found any dust anywhere in New York which had not iron in it."

What seems to be necessary on the technical side of the iron conservation problem, is some inventive development which will assure a more permanent quality in the iron and steel which is manufactured into serviceable forms. A certain amount of wear and tear and unavoidable waste there will always be, but it is by no means impossible that metallurgical and technical development will in the future reduce the wastage to a reasonable minimum. If the great modern steel structures could be looked up as practically permanent, we should have the comfortable assurance that many tons of iron and steel once won from the ore represented a practically permanent addition to the wealth of the world. Great progress has been made within the last few years in the understanding of the corrosion problem and in the art of protecting iron and steel from rapid decay. Several years ago the writer had the honor of presenting before The Franklin Institute a paper on the "Electrolytic Theory of Corrosion." This theory has found a direct application to the manufacture and production

of protective coatings both in the form of paints and of other metals, and careful, systematic tests of these new ideas of protection are more and more strongly corroborative as time goes on. Much remains to be done, however, before the full protection of iron and steel against corrosive influences may be considered a problem solved. The electrolytic explanation of corrosion has shown why it is that hastily made, badly segregated steel rusts more seriously and more quickly than pure, carefully made metal. This knowledge has led to a new development in the metallurgical industry of this country. Processes have been worked out, by means of which iron of extraordinary purity and most excellent quality is now made in open-hearth furnaces on the large scale of operation usual in steel making. The purity of these products is equal and even superior to that of the best Norwegian and Swedish charcoal irons, and there is no question but that they fill a long felt want for a great many industrial purposes. No claim can be made that these pure irons are absolutely rust resistant, but their particular value along this line seems to be that they are slow rusters and that being practically free from impurities, the bad effects due to segregation are reduced to a minimum. It is not always the fact that iron or steel rusts but the manner of its rusting which constitutes a special danger. Just as a chain is no stronger than its weakest link, so also a piece of iron in service may be ruined and discarded even if more than 99 per cent. of its mass and surface is still in good condition. The even texture of the rust which forms upon these pure irons and the absence of pitting effects is one of their prominent characteristics. When provided with an efficient protective coating in addition to their own slow rusting qualities, they appear to be a decided step in advance in the achievement of rust resistant iron. As a basis for the manufacture on a commercial scale, of comparatively cheap and very highly rust resistant alloys, these pure irons hold out a great promise. There are whole series of binary and ternary alloys of iron which have not yet been thoroughly studied even on the laboratory scale. It has already been reported that certain ternary alloys of iron, nickel and copper started from a pure iron base are non-rusting.[9] There is always the hope that a commercial unrustible alloy with the

[9] Clamer, Proc. Am. Soc. for Testing Materials, x, 270 (1910).

strength and valuable physical properties of steel will solve the problem of a permanent industrial metal.

One difficulty that has been met with and overcome in the manufacture of these pure metals lies in the fact that when the attempt is made to burn out all the ordinary impurities that produce segregation, the iron itself is likely to be burned. When this has occurred, the oxygen content of the resulting metal will be high, and segregation of the oxide is almost certain to take place. Fortunately this difficulty has been overcome, and pure iron can now be made with as low an oxygen content as the best steels. On analysis by the Ledebur method of combustion in hydrogen, the writer has examined samples of these pure irons which run as low as 0.015 oxygen. It is probable that an oxygen content of from 0.03 to 0.04 might be considered allowable in metals of this type.

Another project that is interesting along the line of preservation is the study of possible methods of treating structural steel on a manufacturing scale so as to give it a practically unrustible surface. There are a number of processes that have been proposed and some of which are now in use for bringing about this result. The well known Bauer-Barff and Wells processes depend upon already oxidized surfaces. One promising field is along the line of alloying the surface after the steel has already been rolled and shaped. Others again depend upon rolling oxide into the surface and giving the surface another working between specially designed rolls, such as in the Speller process. It is true that all these expedients add to the cost of the products, but, in view of the importance of the problem, it is probable that within reasonable limits the cost will not be a factor.

It is well known that serious damage can be done to structural steel by electrolysis caused by stray currents from high potential electric service lines. In fact, it is perhaps not too much to say that electrolysis threatens the destruction of millions of dollars worth of property in this country. After a few more serious object lessons have been met with by engineers, it is likely that any expedient that promises to reduce the dangers will be welcome. The writer has himself recently been called upon to inspect and report on a full reinforced concrete structure which cost $400,000 to build about four years ago and which has been ruined by electrolysis from escaped railway currents. If this form of

steel tuberculosis is going to attack the great reinforced concrete buildings of the present day, the ultimate damage will be appalling.

The principal methods which are used on a large scale at the present time for the protection of steel consist in the various types of so-called protective coatings. We may consider these under the separate headings of metallic coatings and paints. The electrolytic explanation of corrosion has proved most useful to the technology of protective coatings. The various processes for zinc deposition have been more used than any others. Zinc on theoretical grounds is the most protective metal, owing to the fact that it is strongly electro-positive to iron and will therefore protect it at its own expense as long as it is kept in contact with it. In one very important respect, the subject of zinc protection has not been understood by engineers, manufacturers, and others who are responsible for the production and purchase of galvanized material. It has been generally supposed that any cracking or crazing of the zinc coatings would invite corrosion by allowing moisture and the atmosphere to penetrate to the underlying iron. The effort to overcome this supposed difficulty has led to the application of thin, light coatings of zinc. On the Isthmus of Panama there have been found examples of galvanized sheet that were left there by the French when they abandoned the workings. This galvanized sheet, which must be some thirty to forty years old and which has been exposed under very trying conditions, has steadfastly resisted corrosion. It is true, of course, that these old examples of galvanized sheet were probably hand dipped and were provided with very heavy and efficient zinc coatings. It could not be claimed that the machine galvanized sheet as made to-day would last anything like as long as this, under the same conditions. An example of misdirected zeal on the part of those responsible for specifications for galvanized steel wire has recently been brought to the writer's attention. A specification under which a very large quantity of wire was to be bought stated, among other qualifications, that the wire must be capable of being closely wrapped around another wire of the same diameter, without showing cracking or crazing at the bends. Now, zinc as has been stated, is electro-positive to iron, and when the two metals are in contact, the iron will be protected even if it is entirely exposed and bare. This point has been very clearly brought out

as the result of systematic investigations by the writer and others, and it can be demonstrated by anyone who wishes to take the trouble to solder pieces of zinc and iron together and submit the couple to corrosive influences. Inspection shows that the bare, cut-off ends of galvanized wire do not rust on exposure. Why, then, draw specifications which only succeeded in excluding heavy coatings of zinc, simply because these show cracking and lifting at sharp bends? It would be far better for engineers to specify within possible limits the actual weight of zinc which their galvanized material is to carry, but in default of this it would be better at the present time to buy material that cracks and crazes on severe bending tests than to draw up specifications to preclude this condition.

Next to zinc, the metals most used to protect iron are tin, lead, and the alloys of these two metals which are used in the production of terne plate. Theoretically speaking, neither tin nor lead should ever be used for the protection of iron, for instead of being, like zinc, electro-positive to iron, they are electro-negative. It will therefore be seen that any crack or opening in a protective coating of tin will lead to rapid destruction of the iron at the exposed spot. It appears to be almost impossible to apply a tin coating to the surface of iron, that is free from minute openings known as pin holes. It is for this reason that so much trouble is experienced with the various types of iron which depend upon tin as the protective agent. If a perfectly homogeneous coating of tin could be put upon the surface of iron, the protection might be considered efficient, in spite of the fact that tin is electro-negative to iron, but this would simply be for the reason that tin in itself, when pure, is not a corrodible metal. In contact with iron, however, the burden of attack is thrown upon the iron in the couple, and iron in contact with tin will corrode more rapidly than when left to itself.

Copper, as well as lead and tin, has been proposed as a protective coating for iron, but is open to exactly the same criticism, as it is one of the metals which is strongly electro-negative to iron. Among the electro-positive metals which have not been mentioned, we find both aluminum and magnesium, but up to the present time no alloy of these metals has been evolved, which is suitable in its physical characteristics, even if the cost were not considered prohibitive.

In the field of paint coatings, very great progress has been made in the protection of iron and steel within the last two years.

Four years ago the writer called attention to the fact that the action of the pigment portion of a paint coating, in either promoting or retarding corrosion, had been overlooked.[10] Previous to that time, the attention of engineers and paint technologists had been principally directed to the production of combinations of pigment and vehicle so designed as to be good excluders of moisture and to have other desirable qualities as then understood.

It has already been suggested in this paper that the element iron has been endowed with some very extraordinary properties which especially fit it for the intensive service of mankind. Among these characteristics which it possesses to a unique degree, we may include its power of hardening or taking a temper and the wonderful property of becoming magnetic. Still another wonderful characteristic may be defined as that of passivity or the power of being thrown, by contact with other substances, into a passive condition. The passive condition is not a stable one, nor is it possible by any means to render iron passive and to maintain it in this condition out of contact with the passifying agent. The fact remains the same, however, that while in the passive state iron loses one of its principal characteristics of being extremely active chemically and therefore becomes for the time being uncorrodible. The phenomenon of passivity has been known and studied for many years, and much literature exists on the subject. It is interestingly summed up in the article on iron in the Eleventh Edition of the Encyclopædia Britannica, which has just been published, but time will not allow of a discussion of the subject here. It will suffice to say that the best agents for producing and maintaining the condition, that have been put to practical test for paint coatings, are the slightly soluble chromates and other substances which when acted on by water produce a distinctly alkaline reaction. Pigmentary substances which produce a condition of passivity on the surface of the iron are now generally known and spoken of as inhibitive, because although they cannot be expected to entirely prohibit the rusting of iron, they do serve to maintain the passive condition and therefore check or retard corrosion. A very interesting series of tests involving these prin-

[10] Proc. Am. Soc. for Testing Materials, vols. vii and viii, 1907–8.

ciples has been carried out by the American Society for Testing Materials in co-operation with the Paint Manufacturers' Association of the United States. A number of iron and steel panels treated with paint made from various pigmentary substances, have been exposed to the action of the atmosphere and elements at Atlantic City, N. J., for three years. The latest available report of these tests, which has been published, states that the inspection of the tests has shown that those pigments whose protective value depends upon the value of chromate inhibition, as well as those which produce basic reactions in water suspension, have given a good account of themselves on the test panels. Progressive paint technologists and engineers are now availing themselves of the results of the many investigations which have recently been published along these lines, and a most decided improvement may be expected in our ordinary methods for preservation of iron and steel.

The object of this paper has not been to present new data in regard to the preservation of iron and steel but to briefly summarize and review the general conservation problem. There can be no question that much of the iron which has been allowed to fall into the condition of irretrievable rust or gone to the scrap pile, from which it is unlikely to be again removed and made serviceable, might have been saved if the corrosion and preservation problem had been properly understood by engineers and technologists responsible for its care. It has only been of recent years that engineers have realized that it was unsafe to bring in contact in one construction metals of unlike electrochemical properties. It is, however, true that much destruction of iron has been occasioned by lack of knowledge of this one thing, for even different types of iron and steel will rust each other when connected together and exposed to the action of corrosive influences in the air or water. An Institute of Metals has recently been founded in England, for the special purpose of considering just such important industrial problems as those here referred to. In summarizing this paper which has been written in the hope that it will serve to stimulate general interest on the part of thoughtful persons to the importance of the iron conservation problem, it has been shown that iron, the cheapest and most abundant of the industrial metals, is, after food and clothing, the most indispensable substance which enters into the life-history

of man. A very recent authority has said of iron [11]: "Iron is a very Proteus. It is extremely hard in our files and razors and extremely soft in our horseshoe nails which in some countries the smith rejects unless he can bend them on his forehead. With iron we cut and shape iron; it is extremely magnetic and almost non-magnetic; as brittle as glass and almost as pliable and ductile as copper; extremely springy and springless and dead; wonderfully strong and very weak; conducting heat and electricity easily and again offering great resistance to their passage; here welding readily, there incapable of welding; here very infusible, there melting with relative ease. The coincidence that so indispensable a thing should also be so abundant, that an iron-needing man should be set on an iron-cored globe, certainly suggests design. The indispensableness of such abundant things as air, water, and light is readily explained by saying that their very abundance has evolved a creature dependent upon them, but the indispensable quality of iron did not shape man's evolution, because its great usefulness did not arise until historic times or even, as in the case of magnetism, until modern times."

Whereas it has been shown that the great increase in the per capita consumption of iron by the human race is but a part of the general advance in wealth and civilization, it has also been shown that the intensive use of iron is out of all relation or proportion to the increase of intensivity in the use of the other materials which go to make up the necessities of the race and of civilization. It must, of course, be admitted that the causes of this great increase in the use of iron may be found in the diversion of mankind from purely agricultural to manufacturing pursuits, for nearly all machinery must necessarily be made of iron. Again we have to take into consideration the displacement of wood by iron for ships and bridge building, the use of iron beams, columns and other members used in the construction of modern buildings; the growth of steam and electrical railways, as well as the introduction of iron fencing. In conclusion, it is interesting to note that the three great nations which are the principal iron producers of the world and which are so closely related by ties of blood—Great Britain, the United States and Germany—produced in 1907 81 per cent. of the world's pig-iron and 83

[11] Encyclopædia Britannica, 11th Ed., 1910, vol. xiv, p. 801.

per cent. of its steel; and moreover the four great processes by which practically all the irons and steels are made, namely, the puddling, crucible, the acid and basic varieties of the Bessemer, and open-hearth processes, as well as the great mechanical methods of forging and rolling iron and steel, were invented by Anglo-Saxons, with the possible exception of the open-hearth process in which Great Britain must share with France the credit of the invention.

Gases Occluded in Copper Alloys. G. GUILLERNIN AND B. DELACHANAL. (*Comptes Rendus,* cli, 881.)—From the examination of several special forgeable brasses, bronzes, a phosphor-bronze and two samples of tin, it is concluded that: 1. Special brasses retain occluded from 1 to 30 times their volume of gas, chiefly hydrogen, carbon monoxide and dioxide. 2. In sound castings the gas is almost entirely hydrogen. 3. In unsound castings a larger portion of carbon oxides occur. 4. Hot rolled bars contain less gas than castings. 5. The hydrogen in sound pieces, even when in notable amount, has no injurious effect on the mechanical properties of forgeable brasses. 6. Phosphor-bronze contains very little gas, chiefly carbon dioxide and hydrogen, phosphorus, as in cast-iron and steel, seems to diminish the solubility of hydrogen in the metal. 7. Commercial tin contains a small volume of hydrogen and carbon oxides. 8. None of these metals exhibit the phenomenon of "spitting."

Alloys of Tellurium with Cadmium and Tin. M. KOBAYASHI. (*Zeit. anorg. Chem.,* lxix, 1.)—Thermal analysis shows that tellurium and cadmium combine to form the compound TeCd, which melts at about 104° C. but exists in the melts only in equilibrium with an excess of tellurium. With tin, tellurium forms the compound, TeSn, melting at 780° C. and this forms a eutectic with tellurium containing 86 per cent. of the latter and melting at 393° C. Neither compound forms mixed crystals with its components. Cadmium dissolves tellurium up to 1.2 per cent. at 700° C., and the solubility is probably greater at higher temperatures.

Purification of Waste Water from Pulp Mills. J. G. ROEST. (*Chem. Wochblad,* vi, 106.)—It is well known that clay will remove impurities from liquids. Experiments on its use as a purifier of waste water from pulp mills show that 1½ per cent. of potter's clay is sufficient to precipitate suspended impurities from the waste water. The precipitated waste has an appreciable value as a fertilizer.

A GENERAL FORMULA FOR THE SHEARING DEFLECTION OF BEAMS OF ARBITRARY CROSS SECTION, EITHER VARIABLE OR CONSTANT.

BY

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1. INTRODUCTORY.—In determining the deflection of beams, the effect of shear is usually neglected. The reason for this is that the deflection is usually determined from the equation of the elastic curve, which is based solely on the curvature produced by flexure, and neglects entirely all other forms of deformation such as are produced by shear, torsion, etc.

No general formula for shearing deflection has as yet been derived, although special formulas for the case of constant rectangular and circular cross sections have been obtained, as mentioned below. In what follows the principle of least work is used to obtain a general formula for the shearing deflection of beams of arbitrary cross section, which may be either variable or constant. The same method is also applied to derive the Fraenkel formula for flexural deflection, and it is further shown that all the ordinary formulas for either flexural or shearing deflection are special cases of one or the other of the above. Numerical application of these formulas is then made to the rail of a planer, in which both the cross sectional area and its moment of inertia are variable.

2. DERIVATION OF GENERAL FORMULA FOR SHEARING DEFLECTION.—The principle of least work as applied by Castigliano to the deflection of beams may be stated as follows:

The deflection of the point of application of an external force acting on a beam is equal to the partial derivative of the work of deformation with respect to this force.

This theorem is perfectly general, and applies to the shearing as well as the flexural deflection since both give rise to work of deformation.

The first step is to determine the work of deformation due to shear. For this the following notation will be used.

Let

W_s = work of deformation due to shear
G = modulus of shear (or modulus of rigidity)
q_1 = unit shearing stress
ϕ = unit angular (or shearing) deformation
dA = element of area of cross section
dV = element of volume
dx = element of length

Then Hooke's law for shear may be written

$$\phi = \frac{q_1}{G}.$$

Consequently the unit work of deformation for an infinitesimal parallelopiped of volume dV becomes

$$dW_s = \frac{1}{2} q_1 \phi \, dV = \frac{q_1^2}{2G} dV,$$

and therefore, since $dV = dA\, dx$, the expression for the total work of shearing deformation for the entire beam becomes

$$W_s = \int dx \int \frac{q_1^2 dA}{2G}.$$

Now the method to be used in determining the shearing deflection consists first in assuming a concentrated load K applied to the beam at the point whose deflection is to be determined. This assumed load is used for evaluating the expression for the deflection given by Castigliano's theorem, and having served this purpose is subsequently reduced to zero.

For this purpose let

Q = total shear on any variable section due to the given loading
Q' = shear on any variable section due to a *unit* load at a given point
q = unit shearing stress due to total shear Q, as above
q' = unit shearing stress due to shear Q'

Then for a concentrated load K at any given point, the shear on any section is $Q'K$, and the unit shear at a variable point due to this load is $q'K$. Hence the total unit shear due to both

the actual given loading and the assumed concentrated load K becomes

$$q_1 = q + q'K.$$

Hence the expression for the work of deformation now becomes

$$W_s = \int dx \int \frac{(q + q'K)^2 dA}{2G}$$

Now by Castigliano's theorem, stated above, the actual shearing deflection D_s due to the *given* loading is

$$D_s = \left[\frac{\partial W_s}{\partial K}\right]_{K=0}$$

Performing this differentiation and substitution, we have therefore

$$D_s = \int dx \left[\int \frac{2(q + q'K)\frac{\partial}{\partial K}(q + q'K)dA}{2G}\right]_{K=0}$$

$$= \int dx \int \frac{qq'dA}{G}$$

To simplify this expression, make use of the straight-line law, namely,

$$\frac{q}{Q} = \frac{q'}{Q'}, \quad \text{or} \quad q' = \frac{Q'}{Q}q,$$

whence finally

$$D_s = \int \frac{Q'}{QG}\, dx \int q^2 dA \qquad (1)$$

which is the required general formula for shearing deflection.

3. SPECIAL CASE I.—Constant rectangular section of height h.

For any cross section bounded by parallel sides, the unit shear at any point is given by the expression [1]

$$q = \frac{Q}{bI} \int y dA$$

integrated between the horizontal boundaries, where

b = width of cross section
y = ordinate of given point from neutral axis
I = static moment of inertia of cross section with respect to neutral axis

For a rectangular section of height h this integral becomes

$$\int y dA = \int_y^{\frac{h}{2}} by dy = b \left(\frac{h^2}{8} - \frac{y^2}{2} \right)$$

and consequently

$$q = \frac{Q}{I} \left(\frac{h^2}{8} - \frac{y^2}{2} \right).$$

Substituting this value of q in the second integral of the general formula (1), it becomes for the special case under consideration

$$\int q^2 dA = \frac{Q^2}{I^2} \int_{-\frac{h}{2}}^{\frac{h}{2}} \left(\frac{h^2}{8} - \frac{y^2}{2} \right)^2 b dy$$

$$= \frac{144\, Q^2}{b^2 h^6} \cdot 2 \int_0^{\frac{h}{2}} \left(\frac{h^4}{64} - \frac{h^2 y^2}{8} + \frac{y^4}{4} \right) b dy$$

$$= \frac{6}{5} \frac{Q^2}{A}.$$

[1] Slocum and Hancock, Text-Book on the Strength of Materials, p. 57.

Hence the formula for the shearing deflection reduces in this case to the simple integral

$$D_s = \int_0^l \frac{Q'}{QG}\, dx \left[\frac{6}{5}\,\frac{Q^2}{A}\right]$$

$$= \frac{6}{5}\int_0^l \frac{QQ'}{AG}\, dx. \qquad (2)$$

4. EXAMPLE 1.—Determine the shearing deflection at the centre of a simple beam of constant rectangular cross section due to a single concentrated load at the centre.

Let P denote the load at centre. Then the total shear on any section is

$$Q = \frac{P}{2}$$

Also, assuming a unit load at the point whose deflection is to be determined, namely, the centre, we have

$$Q' = \frac{1}{2}.$$

Substituting these values in the above formula (2),

$$D_s = \frac{6}{5} \cdot 2 \int_0^{\frac{l}{2}} \frac{P dx}{4AG} = \frac{3Pl}{10Gbh}.$$

The relative amount of the shearing deflection as compared with the flexural deflection may be readily determined in this case. Using the same notation, the expression for the flexural or bending deflection D_B is

$$D_B = \frac{Pl^3}{4Ebh^3}$$

where E denotes Young's modulus. Now assuming the relation between the two moduli to be $G = 0.4E$, we have

$$D_s = \frac{3Pl}{4Ebh},$$

and consequently

$$\frac{D_s}{D_B} = \frac{\frac{3Pl}{4Ebh}}{\frac{Pl^3}{4Ebh^3}} = 3\left(\frac{h}{l}\right)^2$$

Hence the relative amounts of the shearing and bending deflection depends in this case on the ratio of the depth of the beam to its length. Thus

$$\text{if } h = \tfrac{1}{20}\, l,\ D_s = 0.0075\, D_B;$$
$$\text{if } h = \tfrac{1}{10}\, l,\ D_s = 0.03 D_B;$$
$$\text{if } h = \tfrac{1}{5}\, l,\ D_s = 0.12\, D_B, \text{ etc.}$$

The relative dimensions for which the shearing deflection ceases to be of importance are thus easily determined.

5. SPECIAL CASE II.—Constant circular cross section of radius r.

For a circular cross section, the integral in the expression for unit shear given under Case I, namely,

$$q = \frac{Q}{bI}\int y\, dA,$$

becomes

$$\int y dA = 2\int_y^r \sqrt{r^2 - y^2}\ y dy = \frac{2}{3}\left(r^2 - y^2\right)^{\frac{3}{2}}$$

or, if the length of the chord corresponding to the ordinate y is denoted by x, then since

$$\sqrt{r^2 - y^2} = \frac{x}{2}$$

this becomes

$$\int y dA = \frac{2}{3}\left(r^2 - y^2\right)^{\frac{3}{2}} = \frac{x^3}{12}$$

and hence

$$q = \frac{Q}{bI}\int ydA = \frac{Qx^2}{3\pi r^4}$$

since

$$b = x \text{ and } I = \frac{\pi r^4}{4}.$$

Substituting this value of q in the second integral of the general formula for shearing deflection (1), we have

$$\int q^2 dA = \int \frac{Q^2x^4}{(3\pi r^4)^2}\, x dy = \frac{32Q^2}{(3\pi r^4)^2}\int_{-r}^{r}\left(\frac{x}{2}\right)^6 dy$$

$$= \frac{32Q^2}{(3\pi r^4)^2}\int_{-r}^{r}(r^2 - y^2)^3\, dy$$

$$= \frac{64Q^2}{(3\pi r^4)^2}\int_{0}^{r}(r^2 - y^2)^3\, dy = \frac{10}{9}\frac{Q^2}{A}$$

consequently

$$D_s = \int \frac{Q'}{QG}\, dx\left[\frac{10}{9}\frac{Q^2}{A}\right] = \frac{10}{9}\int \frac{QQ'}{AG}\, dx. \qquad (3)$$

6. EXAMPLE. 2.—Determine the shearing deflection at the centre of a simple beam of constant circular cross section and bearing a uniform load.

Let the uniform load be of amount w pounds per unit of length. Then $Q = \frac{wl}{2} - wx$. Also assuming a unit load at the point whose deflection is to be determined, namely, the centre, we have $Q' = \frac{1}{2}$. Hence in the present case

$$D_s = \frac{10}{9}\cdot 2\int_0^{\frac{l}{2}} \frac{\left(\frac{wl}{2} - wx\right)\frac{1}{2}}{AG}\, dx = \frac{5wl^2}{36\pi r^2 G}.$$

The relative amount of the shearing deflection as compared with the flexural deflection is in this case given by the ratio

$$\frac{D_s}{D_B} = \frac{\frac{5wl^2}{36\pi r^2 G}}{\frac{5wl^4}{384EI}}$$

and assuming as above that $G = 0.4E$, and also denoting the depth of the beam by $h = 2r$, this becomes

$$\frac{D_s}{D_B} = \frac{5}{3}\left(\frac{h}{l}\right)^2.$$

For a circular cross section, therefore, the shearing deflection is of less relative importance for a given ratio of length to depth than for a rectangular cross section. Thus

$$\text{if } h = \tfrac{1}{10}\, l,\ D_s = 0.016\, D_B \text{ etc.}$$

The above simple examples are given to illustrate the application of the general formula (1). The application of this formula to a beam of variable cross section is deferred to Article 12, below.

7. DERIVATION OF GENERAL FORMULA FOR FLEXURAL DEFLECTION.—The ordinary method of determining flexural or bending deflection is by computing the ordinate to the elastic curve at the required point. This method has the disadvantage that each case of loading must be treated as a separate problem. A general formula, however, has been derived by Professor Fraenkel, although for some reason it does not seem to have found its way into any current texts and is therefore not generally known. The proof of this formula is usually obtained by equating the internal work of deformation to the work of the external forces. This is in fact the only proof ever seen by the writer. The Fraenkel formula, however, may be obtained from the principle of least work by applying Castigliano's theorem in precisely the same manner as applied above in deriving the general formula for shearing deflection.

For this purpose let

W_B = work of deformation due to bending
E = Young's modulus
M_1 = bending moment at any cross section
I = static moment of inertia of cross section with respect to neutral axis

Then it is well known that the work of flexural deformation for the entire beam is given by the formula [2]

$$W_B = \int \frac{M_1^2 dx}{2EI}.$$

Now in order to apply Castigliano's theorem to this expression, assume a concentrated load K applied to the beam, which is subsequently reduced to zero.

Let

M = moment at any section due to given loading
M' = moment at any section due to a *unit* load at a given point.

Then for a load K at the given point, the moment at any section due to this load may be written KM' and consequently the total moment due to the actual loading and the assumed load K becomes

$$M_1 = M + KM'.$$

Hence the above expression for the work of flexural deformation now becomes

$$W_B = \int \frac{(M+KM')^2 dx.}{2EI}$$

Now by Castigliano's theorem the actual deflection due to the given loading is

$$D_B = \left[\frac{\partial W_B}{\partial K}\right]_{K=0}$$

[2] *Ibid.*, p. 84.

and applying this to the expression for W_B, we have

$$D_B = \left[\int \frac{2(M+KM')\dfrac{\partial}{\partial K}(M+KM')\,dx}{2EI}\right]_{K=0}$$

or, simplifying,

$$D_B = \int \frac{MM'}{EI}\,dx \qquad (4)$$

which is the required general formula for flexural deflection.

All the ordinary formulas for the flexural deflection of beams under various loadings and methods of support are simply special cases of this general formula (4), as illustrated by the following examples.

8. EXAMPLE 3. —Find the flexural deflection at the centre of a simple beam of constant cross section bearing a single concentrated load P at the centre.

Here $M = \frac{Px}{2}$, and applying a unit load at the point whose deflection is desired, namely, the centre, $M' = \frac{x}{2}$. Consequently

$$D_B = 2\int_0^{\frac{l}{2}} \frac{Px^2dx}{4EI} = \frac{Pl^3}{48EI}.$$

9. EXAMPLE 4.—Find the flexural deflection at the centre of a simple beam of constant cross section carrying a uniform load over the entire span.

In this case

$$M = \frac{wlx}{2} - \frac{wx^2}{2}, \text{ and } M' = \frac{x}{2},$$

Consequently

$$D_B = 2\int_0^{\frac{l}{2}} \left(\frac{wlx^2}{4} - \frac{wx^3}{4}\right)\frac{dx}{EI} = \frac{5wl^4}{384EI}.$$

10. EXAMPLE 5.—Find the flexural deflection at the centre of a beam of constant cross section fixed at both ends and bearing a single concentrated load at the centre.

The first step in this problem is to determine the moment at one support. This is determined from the condition that the deflection at the support is zero.

Applying a load of unity at the left support we have for sections on either side of the centre

$$\text{Left of centre} \begin{cases} M = M_0 - \frac{Px}{2} \\ M' = x \end{cases}$$

$$\text{Right of centre} \begin{cases} M = M_0 - \frac{Px}{2} + P\left(x - \frac{l}{2}\right) \\ M' = x \end{cases}$$

where M_0 denotes the moment at the left support. Substituting these values in the condition

$$D_B \text{ at support} = 0$$

we have

$$D_B = \frac{2}{EI}\int_0^{\frac{l}{2}} \left(M_0 - \frac{Px}{2}\right) x\,dx + \frac{2}{EI}\int_{\frac{l}{2}}^{l} \left(M_0 x + \frac{Px^2}{2} - \frac{Plx}{2}\right) dx$$

$$= \frac{2}{EI}\left[\frac{M_0 x^2}{2} - \frac{Px^3}{6}\right]_0^{\frac{l}{2}} + \frac{2}{EI}\left[\frac{M_0 x^2}{2} + \frac{Px^3}{6} - \frac{Plx^2}{4}\right]_{\frac{l}{2}}^{l} = 0$$

whence

$$M_0 = \frac{Pl}{8}.$$

Proceeding now to find the centre deflection, we have

$$M = M_0 - \frac{Px}{2} = \frac{Pl}{8} - \frac{Px}{2}$$

$$M' = \frac{l}{8} - \frac{x}{2}$$

and consequently

$$D_B = \frac{2}{EI}\int_0^{\frac{l}{2}} \left(\frac{Pl^2}{64} - \frac{Plx}{16} - \frac{Plx}{16} + \frac{Px^2}{4}\right) dx = \frac{Pl^3}{192EI}$$

11. EXAMPLE 6.—Find the flexural deflection at the centre of a beam of constant cross section, fixed at both ends and carrying a uniform load over the entire span.

Let

M_0 = moment at left support

w = load in $\frac{\text{lbs.}}{\text{ft.}}$

Then

$$M = M_0 - \frac{wlx}{2} + \frac{wx^2}{2}.$$

$$M' = x$$

To find M_0 apply the condition that the deflection at the support is zero. Then

$$D_B \text{ at left support} = \frac{1}{EI}\int_0^l \frac{\left(M_0 x - \frac{wlx^2}{2} + \frac{wx^3}{2}\right) dx}{EI}$$

$$= \frac{1}{EI}\left[\frac{M_0 x^2}{2} - \frac{wlx^3}{6} + \frac{wx^4}{8}\right]_0^l = 0$$

whence

$$M_0 = \frac{wl^2}{12}$$

To find the centre deflection we have therefore

$$M = M_0 - \frac{wlx}{2} + \frac{wx^2}{2} = \frac{wl^2}{12} - \frac{wlx}{2} + \frac{wx^2}{2}$$

$$M' = \frac{l}{8} - \frac{x}{2} \text{ (from Example 5, Art. 10)}$$

and consequently

$$D_B \text{ at centre} = \frac{2}{EI}\int_0^{\frac{l}{2}} \left(\frac{wl^2}{96} - \frac{wl^2 x}{16} + \frac{wlx^2}{16} - \frac{wl^2 x}{24} + \frac{wlx^2}{4} - \frac{wx^3}{4}\right) dx$$

$$= \frac{wl^4}{384EI}.$$

12. VARIABLE CROSS SECTION.—The preceding examples have been given to illustrate the generality of the formulas deduced, and the method of application. By reason of their

generality, the application of the formulas may be extended to beams of variable cross section, which cannot be readily handled by ordinary methods.

The simplest law of variation is that in which the moment of inertia and cross sectional area vary linearly along the axis of the beam. This is the law which has been found to apply in the case of the planer rail considered in Article 19 below, and is probably the one which will be found to apply most generally.

Let I_0 denote the moment of inertia at the left support. Then in the case of linear variation, the moment of inertia at any variable point x is given by

$$I = I_0 + kx \qquad \left(o \leqq x, \leqq \frac{l}{2}\right)$$

where k is a constant depending on the form of the beam. From what precedes the total deflection due to flexure and shear is given by the expression

$$D = \int \frac{MM'}{EI}\,dx + \int \frac{Q'}{QG}dx \int q^2 dA \qquad (5)$$

The flexural deflection, given by the first term of this expression, will first be calculated.

Assume that the beam is fixed at both ends and bears a concentrated load P at the centre. Let M_0 denote the moment at the left support. To determine M_0 assume a load of unity at the left support and apply the condition that the deflection at the support is zero, as in Examples 5 and 6 above. Taking sections on either side of the centre at a distance x from the left support, we have, respectively

$$\text{Left of centre} \begin{cases} M = M_0 - \dfrac{Px}{2} \\ M' = x \\ I = I_0 + kx \end{cases}$$

$$\text{Right of centre} \begin{cases} M = M_0 - \dfrac{Px}{2} + P\left(x - \dfrac{l}{2}\right) \\ M' = x \\ I = I_0 + k\,(l - x) \end{cases}$$

Therefore the condition

$$D_B \text{ at support} = 0$$

becomes

$$D_B \text{at support} = \int_0^{\frac{l}{2}} \frac{\left(M_0 - \frac{Px}{2}\right) x dx}{E(I_0 + kx)} + \int_{\frac{l}{2}}^{l} \frac{\left(M_0 x + \frac{Px^2}{2} - \frac{Plx}{2}\right) dx}{E(I_0 + kl - kx)} = 0$$

whence, by integration and substitution of limits,

$$M_0 = \frac{Pl}{4 \log \frac{2I_0 + kl}{2I_0}} - \frac{PI_0}{2k}.$$

To simplify the form of this expression, let

$$R \equiv \log \frac{2I_0 + kl}{2I_0}$$

and

$$H \equiv \frac{l}{4R} - \frac{I_0}{2k}$$

Then

$$M_0 = P\left(\frac{l}{4R} - \frac{I_0}{2k}\right) = PH.$$

Having determined M_0, the flexural deflection at the centre may be found by applying the unit load at this point and proceeding as above. For this purpose

$$M = M_0 - \frac{Px}{2} = P\left(H - \frac{x}{2}\right)$$

$$M' = H - \frac{x}{2}$$

and consequently

$$D_B \text{ at centre} = 2 \int_0^{\frac{l}{2}} \frac{P\left(H - \frac{x}{2}\right)^2 dx}{E(I_0 + kx)}$$

$$= \frac{2PH^2}{E} \int_0^{\frac{l}{2}} \frac{dx}{I_0 + kx} + \frac{2PH}{E} \int_0^{\frac{l}{2}} \frac{x dx}{I_0 + kx} + \frac{P}{2E} \int_0^{\frac{l}{2}} \frac{x^2 dx}{I_0 + kx}$$

which, upon integration and substitution of limits, reduces to the comparatively simple form

$$D_B \text{ at centre} = \frac{Pl}{16kE}(l - 8H). \tag{6}$$

13. DISTRIBUTION OF SHEAR OVER VARIABLE SECTION.—In order to apply the general formula for shearing deflection to the case of a variable cross section, it is first necessary to determine the law of distribution of shear over the section. That is to say, it is necessary to obtain a formula for a variable section corresponding to the formula

$$q = \frac{Q}{bI}\int ydA$$

for a constant cross section, as used in Articles 3 and 5 above. For this purpose, proceed as follows:

The ordinary formula for bending stress at any point in a beam is

$$p = \frac{My}{I}$$

Now differentiate this expression with respect to x, remembering that both I and M are functions of x. Then

$$\frac{dp}{dx} = \frac{\frac{dM}{dx}yI - \frac{dI}{dx}My}{I^2}$$

or, since

$$\frac{dM}{dx} = Q \text{ and } \frac{dI}{dx} = k,$$

this becomes

$$\frac{dp}{dx} = \frac{Qy}{I} - \frac{kMy}{I^2}$$

Now let z denote the width of the cross section at any point, and q the unit shear acting over the area zdx (Fig. 1). Since

this equilibrates the difference in normal stress on adjacent sections, we have

$$\int dp\, dA = qz\, dx$$

Therefore, eliminating dp between this equation and the one preceding, we have

$$\int \left(\frac{Qy}{I} - \frac{kMy}{I^2}\right) dA = qz$$

whence

$$q = \frac{QI - kM}{zI^2} \int y dA \qquad (7)$$

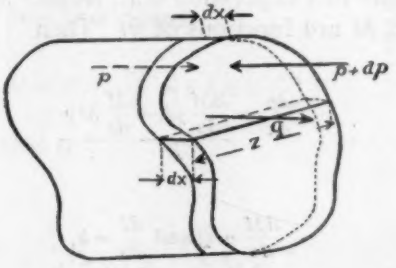
which is the required law of distribution of shear.

For a constant cross section, $k = o$ and $z =$ constant, say b, in which case equation (7) reduces to

$$q = \frac{Q}{bI} \int y dA$$

as in Articles 3 and 5 above.

FIG. 1.



In Article 3 it was found that the second integral in the general formula became for the case there considered

$$\int q^2 dA = \frac{6}{5} \frac{Q^2}{A} = 1.2 \frac{Q^2}{A}$$

and in Article 5 it became

$$\int q^2 dA = \frac{10}{9}\frac{Q^2}{A} = 1.11\,\frac{Q^2}{A}.$$

The corresponding expressions for values of q given by equation (7) will now be evaluated for four different forms of variable cross section.

14. VARIABLE RECTANGULAR SECTION.—
For a rectangular cross section

$$\int y dA = z\left(\frac{h^2}{8} - \frac{y^2}{2}\right)$$

and consequently

$$q = \frac{QI - kM}{I^2}\left(\frac{h^2}{8} - \frac{y^2}{2}\right).$$

Hence

$$\int q^2 dA = \frac{(QI - KM)^2}{I^4}\int_{-\frac{h}{2}}^{\frac{h}{2}}\left(\frac{h^2}{8} - \frac{y^2}{2}\right)^2 z dy$$

$$= \frac{6}{5}\,\frac{(QI - kM)^2}{I^2 A} \tag{8}$$

15. VARIABLE CIRCULAR SECTION.—
For a circular cross section

$$\int y dA = \frac{2}{3}\left(r^2 - y^2\right)^{\frac{3}{2}} = \frac{z^3}{12}$$

Hence

$$q = \frac{QI - kM}{I^2}\cdot\frac{z^3}{12}$$

and consequently

$$\int q^2 dA = \frac{(QI - kM)^2}{144 I^4}\int z^4 dA = \frac{64(QI - kM)^2}{144 I^4}\int_0^r (r^2 - y^2)^{\frac{4}{2}} dy$$

$$= \frac{10}{9}\,\frac{(QI - kM)^2}{I^2 A} \tag{9}$$

It is evident from the similarity of these expressions with those previously deduced that the integral

$$\int q^2 dA$$

is some constant multiple of the quantity

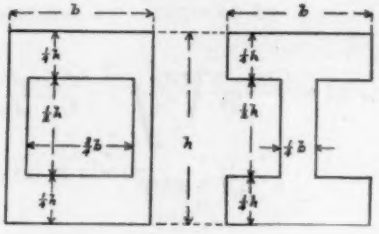
$$\frac{(QI - kM)^2}{I^2 A}.$$

It therefore becomes important to determine the range of values of this constant for typical forms of cross section.

16. HOLLOW RECTANGLE OR **I**.—

For this purpose consider first a hollow rectangle or **I** of

FIG. 2.



the relative dimensions shown in Fig. 2. In this case for y between $\frac{h}{4}$ and $\frac{h}{2}$ we have

$$\int ydA = \int_{y\left(>\frac{h}{4}\right)}^{\frac{h}{2}} zydy + \int_{y\left(<\frac{h}{4}\right)}^{\frac{h}{4}} z'ydy = b\left(\frac{h^2}{8} - \frac{y^2}{2}\right)$$

whereas for y between 0 and $\frac{h}{4}$,

$$\int ydA = \int_{\frac{h}{4}}^{\frac{h}{2}} zydy + \int_{y}^{\frac{h}{4}} z'ydy = b\left(\frac{13h^2}{128} - \frac{y^2}{8}\right)$$

Consequently, for $\frac{h}{4} < y < \frac{h}{2}$ we have

$$q = \frac{QI - kM}{I^2}\left(\frac{h^2}{8} - \frac{y^2}{2}\right)$$

and for $0 < y < \frac{h}{4}$ we have $\left(\text{since } z = \frac{b}{4}\right)$

$$q = \frac{QI - kM}{I^2}\left(\frac{13}{32}h^2 - \frac{y^2}{2}\right)$$

Substituting these values of q in the integral

$$\int q^2 dA,$$

and integrating between the given limits we have therefore

$$\int q^2 dA = \frac{(QI - kM)^2}{I^4}\left[\int_{\frac{h}{4}}^{\frac{h}{2}} 2\left(\frac{h^2}{8} - \frac{y^2}{2}\right)^2 b\,dy + \int_0^{\frac{h}{4}} \frac{1}{2}\left(\frac{13}{32}h^2 - \frac{y^2}{2}\right) b\,dy\right]$$

$$= \frac{(QI - kM)^2\, bh^5}{I^4} \cdot \frac{262}{12288}.$$

In the present case, however, it is found that $I = \frac{29}{384}bh^3$ and $A = 5/8\,bh$, and consequently the above expression reduces to

$$\int q^2 dA = \frac{(QI - kM)^2 bh^5}{I^2\left(\frac{29}{384}\right)^2 b^2h^6} \cdot \frac{262}{12288}$$

$$= 2.099\,\frac{(QI - kM)^2}{I^2 A}. \qquad (10)$$

Now let the relative dimensions of the rectangle or **I** be

altered to those shown in Fig. 3. Then proceeding as above we have for

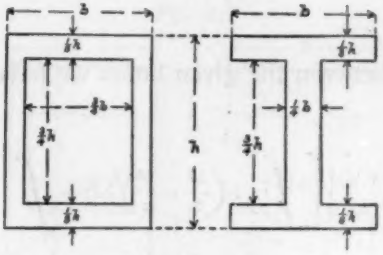
$$\frac{3h}{8} < y < \frac{h}{2}$$

$$\int ydA = \int_{y}^{\frac{h}{2}} zydy = b\left(\frac{h^2}{8} - \frac{y^2}{2}\right)$$

and for $o < y < \frac{3h}{8}$

$$\int ydA = \int_{\frac{3h}{8}}^{\frac{h}{2}} zydy + \int_{y}^{\frac{3h}{8}} z'ydy = \frac{37\,bh^3}{512} - \frac{by^2}{8}$$

FIG. 3.



Hence the corresponding values of q are

$$q = \frac{QI - kM}{I^2}\left(\frac{h^2}{8} - \frac{y^2}{2}\right) \qquad \frac{3h}{8} < y < \frac{h}{2}$$

and

$$q = \frac{QI - kM}{I^2}\left(\frac{37h^2}{128} - \frac{y^2}{2}\right) \qquad o < y < \frac{3h}{8}.$$

The integral in question becomes therefore

$$\int q^2 dA = \frac{(QI - kM)^2}{I^4}\left[2\int_{\frac{3h}{8}}^{\frac{h}{2}}\left(\frac{h^2}{8} - \frac{y^2}{2}\right)^2 bdy + \frac{1}{2}\int_{o}^{\frac{3h}{8}}\left(\frac{37h^2}{128} - \frac{y^2}{2}\right)^2 bdy\right]$$

$$= \frac{(QI - kM)^2}{I^4} bh^5 \cdot \frac{13349}{983040}$$

or, since in this case $A = \frac{7}{16}\,bh$ and $I = \frac{175bh^3}{3072}$, this becomes

$$\int q^2 dA = 1.83\,\frac{(QI - kM)^2}{I^2 A} \qquad (11)$$

17. GENERAL FORMULA FOR SHEARING DEFLECTION, VARIABLE CROSS SECTION.—It is evident, therefore, that for any ordinary form of cross section the constant which multiplies the expression $\frac{(QI - kM)^2}{I^2 A}$ lies between 1 and 2. Let this constant be denoted by n. Then the general formula for the shearing deflection of a beam of variable cross section may be written

$$D_s = n \int \frac{Q'}{QG}\,\frac{(QI - kM)^2}{I^2 A}\,dx. \qquad (12)$$

If $k = 0$, *i.e.*, the cross section is constant, this reduces to the special form used in Articles 3 and 5.

18. APPLICATION.—Now consider the special application of the result just obtained to a beam of variable cross section, fixed at both ends, and carrying a single concentrated load at the centre. Assume, moreover, that the moment of inertia and the cross sectional area both vary linearly. Then we have

$$I = I_0 + kx \qquad Q = \frac{P}{2}$$
$$A = A_0 + cx$$
$$M_0 = PH \qquad Q' = \frac{1}{2}$$

Substituting these values in the expression for the shearing deflection D_s, given by equation (12), we have

$$D_s \text{ at centre} = \frac{2Pn}{G}\int_0^{\frac{l}{2}} \left[\frac{1}{4(A_0 + cx)} - \frac{k\left(H - \frac{x}{2}\right)}{(I_0 + kx)\,(A_0 + cx)}\right.$$
$$\left. + \frac{k^2\left(H - \frac{x}{2}\right)^2}{(I_0 + kx)^2\,(A_0 + cx)}\right] dx$$

which by integration and reduction finally becomes

$$D_s \text{ at centre} = \frac{Pn}{2Gc}\left\{\frac{ckl(I_0+2kH)^2}{I_0(kA_0-cI_0)(2I_0+kl)}+4\log\frac{2I_0+kl}{2I_0}\right.$$
$$\left.-\left[1+\frac{k(2cH+A_0)}{A_0k-cI_0}\right]^2\log\frac{A_0(2I_0+kl)}{I_0(2A_0+cl)}\right\} \qquad (13)$$

19. NUMERICAL APPLICATION TO PLANER RAIL.—As a numerical application of formulas (6), Article 12, and (13), Article 18, consider the deflection of the rail of a standard planer, the one here used for illustration being that shown in Fig. 4. The distance between supports is in this case $l = 35\frac{1}{2}$. This distance was divided up into 8 equal parts and a cross section of the rail plotted to scale at each point of division, these cross sections being thus 4.44 inches apart. In this way it was found that the moment of inertia varied linearly to a close approximation, *i.e.*, $I = I_0 + kx$ where in the present case $I_0 = 45$ and $k = 20$. It was also found that the area followed approximately the straight line law, *i.e.*, $A = A_0 + cx$, where $A_0 = 25$ and $c = 1.4$.

Now for purposes of computation, assume a unit load of 1000 pounds on the point of the tool. Then the flexural and shearing deflections are obtained by substituting the following numerical quantities in formulas (6) and (13).

$P = 1000$ lbs.
$n = 1.8$
$E = 15{,}000{,}000 \frac{\text{lbs.}}{\text{in.}^2}$
$G = 6{,}000{,}000 \frac{\text{lbs.}}{\text{in.}^2}$
$I_0 = 45$ in.^{4}
$k = 20$ in.^{3}
$A_0 = 25$ in.^{2}
$c = 1.4$ in.
$l = 35.5$ in.
$R = \log_e \frac{2I_0+kl}{2I_0} = 2.184802$
$H = \frac{l}{4R} - \frac{I_0}{2k} = 2.93715$

Hence from formula (6), Article 12, the flexural deflection at the load is found to be

$$D_B = 0.00008877 \text{ in.}$$

and similarly, from formula (13), Article 18, the shearing deflection at the load is found to be

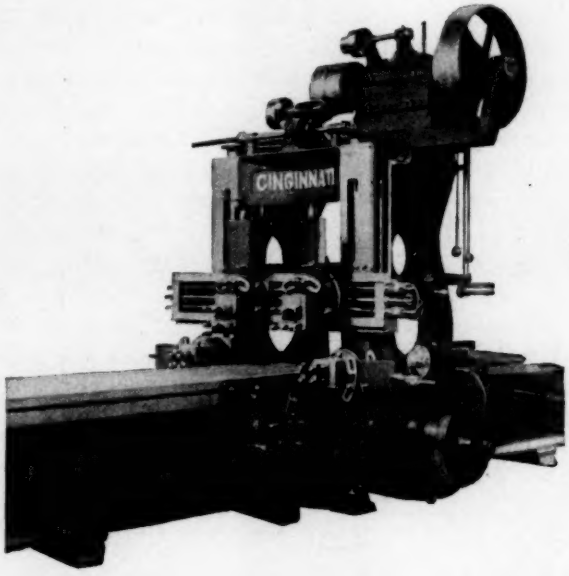
$$D_s = 0.00009766 \text{ in.}$$

It is noteworthy that the shearing deflection is found to be in excess of the flexural deflection. This is due partly to the fact

that, for any beam, as the ratio of depth to length increases the ratio of shearing to flexural deflection also increases, as shown in Articles 4 and 6, but more especially in the present case to the fact that the rail is designed entirely for flexural rigidity, the material being concentrated where the moment is greatest, without reference to the shear, which is constant throughout.

For the planer rail here considered, the load on the point of the tool also produces a torsional strain in addition to shear and

FIG. 4.



flexure, the amount of the torque being equal to the load on the tool multiplied by its eccentricity, or distance from the point of the tool to the centre of gravity of the rail. To calculate this torsional deflection, St. Venant's general formula will be used, namely,

$$\theta = \frac{4\pi^2 T I_p}{GA^4} \qquad (14)$$

where

θ = angle of twist per unit of length in radius
T = torque in inch-pounds
I_p = polar moment of inertia of cross section in biquadratic inches.

Assuming the distance from the point of the tool to the centre of gravity of the rail to be 12 inches for the rail here considered, the torque corresponding to a unit load of 1000 pounds is 12,000 inch-pounds. Since both ends of the rail are fixed and the torque applied at the centre, the torsional strain may be computed by taking half the rail and considering it fixed at one end and subjected to a torque of 6000 inch-pounds at the other. Since the rail is of variable section, the angle of twist is computed separately for each of the four segments into which each half of the rail is divided by the given cross sections, using the average polar moment of inertia and average area of cross section for each portion. Each angle of twist for unit length is then multiplied by the length of the segment, namely, 4.44 inches, and the results added for the total angular deflection. The results of this computation are summarized in the following table.

Polar moment of inertia, I_ρ	Average, I_ρ	Area, A	Average, A	Angle of twist in radians
563.28 }	688.43	24.42 }	28.69	.0001781
813.59 }	882.05	32.97 }	35.26	.0001000
950.51 }	1020.19	37.56 }	38.44	.0000818
1089.87 }	1333.18	39.32 }	55.17	.0000252
1576.50 }		71.02 }		
Total angular deflection				.0003851

The deflection at the point of the tool due to torsional strain is obtained by multiplying this angular deflection by the eccentricity, viz., 12 inches, *i.e.*,

$$\text{Torsional deflection} = 12 \times 0.0003851 = 0.0046212 \text{ inch.}$$

Combining the preceding results, the total horizontal deflection at the point of the tool, due to combined flexure, shear, and torsion, is found to be for a unit load of 1000 pounds

$$\text{Total horizontal deflection} = 0.00008877 + 0.00009766 + 0.0046212$$
$$= 0.00480763 \text{ inch.}$$

From formulas 6, 13, and 14 above, it is evident that in each case the deflection is proportional to the load on the tool. Hence the actual deflection under any given load may be found from the above by means of a simple proportion. To find the load on the tool, the best data available are those obtained by Taylor from his experiments on cutting metals. These experiments show that the load on the tool depends primarily on the cross section of chip removed, which for cast-iron has been found to be about 99 tons (2000 pounds) per square inch of cross section of chip. Assuming a maximum cut of $\frac{1}{8} \times \frac{3}{8}$ inch for the planer here considered, the load on the tool is $\frac{3}{64} \times 99 \times 2000 = 9280$ pounds, and the corresponding deflection $= 9.28 \times 0.0048 = 0.0445$ inch.

For a finishing cut the deflection is of course much less. Thus for a cut of $\frac{1}{64}$ inch with the same tool the load would be $\frac{1}{64} \times \frac{3}{8} \times 99 \times 2000 = 1160$ pounds and the corresponding deflection $= 0.005568$ inch.

It is also to be noted that the deflection computed above is horizontal, and hence, as a rule, does not affect the accuracy of operation of the machine. The vertical deflection is the vertical component of the rotation due to torsional strain. Thus if α denotes the angle of torsion under the assumed unit load of 1000 pounds, we have from the results tabulated above

$$\text{tangent } \alpha = 0.0003851$$

and consequently

$$\text{Vertical deflection} = 12\ (1 - \cos \alpha) = 0.0000084 \text{ inch.}$$

For the maximum load of 9280 pounds corresponding to a cut of $\frac{1}{8} \times \frac{3}{8}$ inch, this becomes

$$\text{Maximum vertical deflection} = 0.00007795 \text{ inch.}$$

As this quantity is so small, the machine may be considered as perfectly rigid for all practical purposes.

Cast-Iron in Piston Rings. H. M. LANE. (*Trans. Amer. Foundryman's Assocn.*, xix, 201.)—As a piston ring is a spring it should not contain less than 0.65 per cent. carbon and may be considered as a steel spring containing silicon, sulphur, phosphorus, manganese, and graphitic carbon. The graphite gives wearing qualities while the combined carbon gives the elasticity, and phosphorus hardness. Piston rings should be cast so as to require very little machining. It is concluded that any given composition of the metal has a certain most efficient thickness; *i. e.*, if the castings are made thinner the metal will be chilled and the machine cost will rise, and if the casting be made thicker, the grain will be more open and the strength rapidly reduced. There should be coöperation between the designer, the foundry and the machine shop.

Available Water-Power of Sweden. T. KOEHN. (*Elektrotech. Zeit.*, xxxi, 1189.)—This deals with the hydro-electric installation already erected by the State, that of Trollhätten, which has now a capacity of 40,000 h. p. while funds for its enlargement to 80,000 h. p. have been voted. A Second Station is to be built in northern Sweden, near Porjus, to be 37,500 h. p. at first, but later to be increased to 100,000 h. p. and to be completed in 1914. A third station of 40,000 h. p. is to be built at Dabälpen, about 130 miles north of Stockholm. Other projects are mentioned and a map shows the position and size of the stations already erected or in course of construction.

Unattended Fog Signal and Lighthouse at Guernsey. ANON. (*Engineer*, cix, 360.)—All the operations are electrically controlled from the mainland by means of an armored multi-cove cable. The cost of the whole work will reach $40,000 as compared with $300,000 which an ordinary lighthouse would cost. Only two keepers will be needed on the mainland in place of four which an isolated lighthouse would require.

Comparison of Aluminum and Copper for Underground Cables. F. C. RAPHAEL AND J. B. SPARKS. (*Elect. Eng.*, vi, 749.)—At present prices aluminum cables are cheaper than copper, whether armored or unarmored. No kind of solder can be recommended for joining aluminum cables, but the skin resistance of the film of oxide is very small, and a method of clamping the ends together under considerable pressure, has given good results for house connections. A cast weld joint has been successful for joining large cables. Sweated terminals have been used, each strand of the cable being tinned with special solder. The cost of laying is another matter, and might be greater for aluminum in certain sizes.

NEW METALLIC FILAMENT LAMPS.

BY

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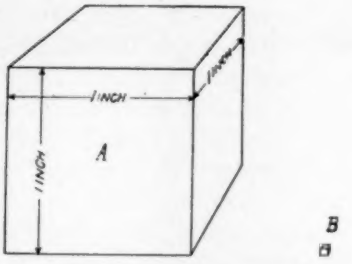
In speaking to you this evening, on the subject of new metallic filament lamps, I wish to deal particularly with the lamps themselves, rather than with their almost endless applications in commercial service.

Although there are several essential parts of an incandescent lamp, the most important part is the light-giving filament. It is rather striking to compare the relatively insignificant bulk of the filament material with the area which it ordinarily illumin-

FIG. 1.



B REPRESENTS AMOUNT OF FILAMENT MATERIAL IN A 60 WATT 110 VOLT MAZDA LAMP

ates. A 60-watt tungsten filament lamp will illuminate very satisfactorily a fairly large room, yet, its filament, if crushed to powder would make a cube of less than one-twentieth of an inch on each side (Fig. 1). Few substances are put to such severe treatment as the bit of matter which composes the filament of an incandescent lamp and the number of materials which can be used for this purpose is consequently very limited.

A study of the necessary physical properties of filament materials in general is interesting and may serve to indicate how

* Presented at the meeting of the Electrical Section held Thursday, January 12, 1911.

difficult it is to secure materials which will meet satisfactorily the several requirements. Before giving any consideration to the physical characteristics, however, we must assume that the material can be put in the form of slender threads, uniform in structure and diameter, for otherwise its use as a filament is precluded.

The physical properties of materials which are of importance in filament study are:

1. Electrical resistance.
2. Vapor tension and melting point.
3. Emissivity.
4. Selectivity.
5. Mechanical strength.

Perhaps the most important physical requisite of a filament material is that it should be a simple electric conductor. It should not only be a good conductor when cold, but it should not become electrolytic when heated as do some metallic oxides. These characteristics are necessary in order to make it possible to operate the lamps on commercial multiple circuits without resort to auxiliary devices and further to make it possible to operate the filaments in a vacuum and thus increase the luminous efficiencies by reducing the loss of heat from the filament. Perhaps it is not generally recognized that the vacuum is an extremely important factor in establishing the value of the luminous efficiency of incandescent filament lamps in general. An example may make this clear.

A tungsten filament which would have required 9.8 watts to maintain it at its normal working temperature in a vacuum, required 63.9 watts or about six and a half times as much power to maintain it at the same temperature (as judged by the resistance) when in a non-oxidizing atmosphere.[1] It is thus apparent that the loss of heat from a filament would greatly reduce the efficiency of light production if the filament were operated in anything but a vacuum.

The filament, being essentially an electric conductor, should have certain electrical characteristics. It is desirable that the

[1] The gas used in this particular case contained quite a little hydrogen and since hydrogen is an exceptionally good medium for heat conduction if the atmosphere had contained no hydrogen, the loss would have been somewhat smaller.

specific resistance of the filament at the working temperature should be rather high in order to make it possible to use comparatively short filaments of considerable diameter in lamps of the candlepowers and voltages which have become standard in the lighting industry. As the specific resistance of carbon is much greater than that of the metals commonly used as filaments, the metal filaments must be much finer and longer to produce lamps comparable with the carbon lamps in wattage and voltage. As a consequence of this difference new types of lamp construction have been developed for the metal filament lamps, some of which are rather elaborate especially in the 200- to 250-volt types where from four to five feet of filament must be disposed of within a comparatively small bulb. The loss of heat from the filament through conduction by the supporting hooks and wires in the case of the tantalum type construction, where the filament is supported at about 23 points, has been shown by Dr. Hyde to be about 7 per cent.

It is desirable that the filaments possess a high positive temperature resistance coefficient since the greater the value of the coefficient, the less the changes in current, wattage and candlepower with fluctuations in applied voltage.

One per cent. increase in voltage will give approximately the following percentage increase in current in lamps of different kinds:

Tungsten	0.59 per cent.
Tantalum	0.72 per cent.
Metallized carbon	0.77 per cent.
Treated carbon	1.07 per cent.
Untreated carbon	1.31 per cent.

If the resistance temperature coefficient were zero (*i.e.*, if the resistance did not change at all with the temperature), the percentage change in current would correspond exactly to the percentage change in voltage. A positive value of the temperature coefficient gives a smaller percentage change in current than in voltage, while a negative temperature coefficient gives a greater percentage change in current than in voltage.

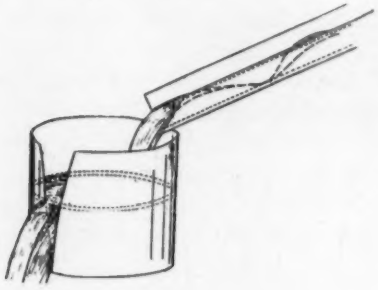
The relative change in wattage and candlepower with voltage differs greatly in lamps with various filament materials, due, probably, in part, to the difference in the resistance temperature coefficients.

One per cent. increase in voltage of a lamp operating at normal efficiency and having filaments of

	Increases wattage.	Increases c. p.
Tungsten	1.59 per cent.	3.73 per cent.
Tantalum	1.72 per cent.	4.27 per cent.
Metallized carbon	1.77 per cent.	4.90 per cent.
Treated carbon	2.07 per cent.	5.69 per cent.
Untreated carbon	2.32 per cent.	7.10 per cent.

These figures would apply only to a change in voltage which takes place rather slowly, *i.e.*, slowly enough to allow for the lag in the filament temperature. When the applied voltage changes with greater rapidity, as in operation on alternating current,

FIG. 2.



the thermal capacity of the filament tends to equalize to a greater or less extent the fluctuations in the filament temperature.

The manner in which the thermal capacity of a filament tends to reduce the fluctuation in temperature (when operating on alternating power supply) may be illustrated by the hydraulic analog of a special reservoir into which water flows at a variable rate. The water put into the reservoir corresponds to the electrical energy put into the filament. The reservoir, we will assume, has a slit in the side through which the water escapes (Fig. 2). The water flowing out represents the energy dissipated from the filament by radiation, conduction and connection. Although the rate of inflow may vary over a wide range, the level of the water in the reservoir fluctuates but very little and the rate of outflow remains nearly uniform. The greater the diameter of the reservoir, compared with the rate of inflow, and

the greater the frequency of the pulsating supply, the less the fluctuation in water level and in outflow. The diameter of the reservoir corresponds to the thermal capacity of the filament and the fluctuation of water level represents fluctuation in filament temperature. In the case of the filament, the greater the thermal capacity and the greater the frequency of the alternating power supply, the less will be the fluctuation in temperature and in candlepower throughout each cycle.

In the case of tungsten filament lamps, the cold resistance is only about one-eleventh of the resistance at the temperature of normal operation. These lamps therefore take a momentary starting current above that of normal operation, when thrown onto multiple circuit. The effect of this momentary starting current is extremely small and it is not necessary to discuss it further than to mention its existence.

The filament of an incandescent lamp must not only meet certain requirements of an electric conductor but it must also possess certain characteristics as a luminous radiator. The latter condition greatly limits the number of materials which can be used as filaments of incandescent lamps. The light of incandescent lamps is produced by temperature radiation as distinguished from luminescence or florescence. It is therefore desirable to operate the incandescent filament at as high a temperature as possible in order that the proportion of the energy radiated within the visible spectrum and hence the efficiency of light production may be high.

The maximum temperature at which it is possible to commercially operate a certain material in the high vacuum of an incandescent lamp bulb is determined by its rate of disintegration if the vapor tension is high and by its melting point if the vapor tenson is low. The high vapor tension of the carbon filament which is shown by its tendency to evaporate at temperatures far below its melting point makes it impossible to commercially operate carbon filaments at the normal working temperature of the tungsten filament. Obviously any filament can be operated for a short time at a temperature and efficiency far above that at which it gives a reasonable commercial life, but such a gain in efficiency is secured only by the sacrifice of the lamp itself. On the other hand, operation at a low temperature requires a correspondingly greater consumption of energy for the light pro-

duced, and this cannot be compensated for by the decreased rate of depreciation of the filament. The efficiencies at which the various filaments should operate in commercial service have been determined by a consideration of the economy of light production, and lamps are rated at voltages corresponding as nearly as possible to such efficiencies.

Not only do the various filament materials differ in their ability to withstand high operating temperatures but they differ also in their radiating properties. The amount of energy which can be radiated from equal surfaces of different materials at the same temperature is found to vary considerably. The emissivity or mere ability to radiate energy does not affect the luminous efficiency but it plays an important part in determining the lengths and diameters of filaments in the commercial lamps.

The study of the radiating properties of various materials leads eventually to a consideration of their ability to radiate relatively different quantities of energy in certain portions of the spectrum when at the same true temperature. When a material tends to radiate relatively more energy in the visible spectrum than other bodies at the same temperature an important means of securing high luminous efficiency is offered through its use.

To show to what an extent such selective radiation may assist in attaining high efficiencies, reference may be made to the paper by Dr. Hyde presented before this Society last March.[2] The data given by Dr. Hyde show that when filaments of various materials are operated at temperatures which give a color match with an untreated carbon filament, the relative efficiency of light production varies over a considerable range, depending both upon the radiating material and upon the temperature of the untreated filament with which a color match is made.

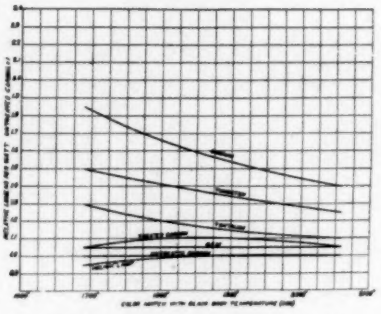
Without going into further detail the data may be presented in the form of curves in Figure 3 simply to emphasize the differences which exist between various substances, as luminous radiators. If the materials could be compared at the same true temperatures instead of at the temperatures at which they gave the same color match the gain in efficiency due to selective radia-

[2] "The Physical Production of Light," by Edward P. Hyde, Journal of the Franklin Institute, July, 1910.

tion would, in all probability be more pronounced.[3] Dr. Hyde concludes that the metal osmium would be possibly at least 40 or 50 per cent. more efficient as a luminous radiator than the untreated carbon. A consideration of the curves would indicate a similar possible gain in efficiency of from 25 to 30 per cent. in the case of tungsten and from 10 to 15 per cent. in the case of tatalum.

Selectivity and emissivity are often confused and effects at least partly due to low emissivity are sometimes ascribed to selectivity. One writer[4] has recently attempted to show the selectivity of tungsten with respect to carbon by calling attention to the

FIG. 3.



Relative lumens per watt at color match.
(Data from paper by Dr. E. P. Hyde.)

fact that when operating at the same luminous efficiency, the carbon filament shows a smaller surface area per candle than the tungsten. He concludes that the carbon filament must therefore be at a higher temperature than the tungsten to give the same luminous efficiency and that the latter must evidently be a selective radiator. While his conclusion is fortunately correct, the method of demonstration is not rigorous, for the difference in surface per candle at the same luminous efficiency need

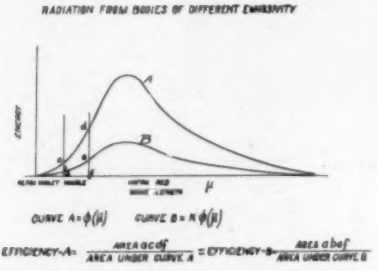
[3] In connection with this subject, I may further refer to the paper on the "Reflecting Power of Various Metals," by W. W. Coblentz (Journal of the Franklin Institute, September, 1910). A number of materials show properties of selective reflection which indicate that they would make efficient luminous radiators.

[4] Hartwig von Löte, Lecture before the Elektrotechniche Verein in Vienna.

not indicate a difference in temperature due to the fact that the emissivity of the two filaments may be different.

For example, we might have two filaments of exactly the same length and diameter, having the same relative distribution of energy throughout the entire spectrum when at the same temperature, but differing in emissivity so that the total energy radiated by the one would be but one-third of that radiated by the other. When at the same temperature these two filaments might have energy distribution curves, as shown in Fig. 4. Now since the two bodies are assumed to have the same distribution of energy, their efficiencies of light production as measured by the ratio of energy radiated in the visible spectrum, to the total energy radiated must be the same. However, due entirely to its lower emissivity, the filament of the one material (B) would

FIG. 4.


RADIATION FROM BODIES OF DIFFERENT EMISSIVITY
ENERGY
A
B
μ
CURVE A = φ(μ)
CURVE B = K φ(μ)
EFFICIENCY-A = AREA acdf / AREA UNDER CURVE A = EFFICIENCY-B = AREA abef / AREA UNDER CURVE B

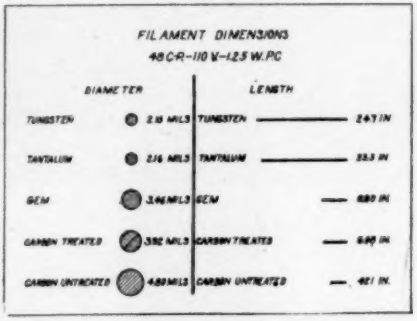
give just one-third the candlepower of the filament of the material (A) possessing a higher emissivity. In this case the temperatures are identical, and in spite of the fact that the surface area per candle differs greatly, there is no selectivity since we assumed to begin with that the distribution of energy throughout the spectrum was the same for each material. Consequently the assumption that the surface area per candlepower indicates a selectivity is unwarranted, for it is quite conceivable that a material could have such a low emissivity as to give even a greater area per candle than tungsten when measured at the same luminous efficiency and still be far less selective.

The metal osmium has been shown to possess the property of selective radiation in the visible spectrum to a high degree, but the difficulty of working it and its relatively low melting point have made its commercial use impracticable. Tungsten, while

not quite as selective as osmium, is more plentiful, and moreover it can be operated commercially at a higher temperature and efficiency so that it is a more desirable filament material than osmium in spite of the greater selectivity of the latter substance. Investigation as to selectivity of various substances is constantly being carried on and the future may reveal materials which meet the severe requirements imposed on incandescent filaments in general, which are even more selective than those known to-day.

A comparison of length and diameter of filaments of various kinds, which would be required to produce lamps of identically the same candlepower and voltage at the same luminous efficiency, may serve to illustrate concretely the manner in which

FIG. 5.



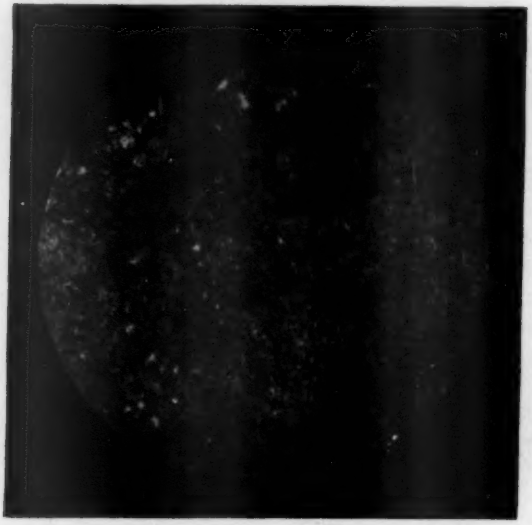
variations in the specific resistance and in the radiating properties of various materials will effect the filament dimensions.

In order to produce lamps of 48 candlepower, 110 volts, 1.25 w.p.c., the filament dimensions would be approximately as shown in Fig. 5. The difference in the lengths of the metal filament and the carbon filaments is seen to be particularly great.

The foregoing discussion may indicate some of the physical properties of a material which are of importance in determining its suitability for use as an incandescent filament. It is, however, one thing to determine what materials would theoretically make good filaments—judged from the several stand-points previously mentioned, but it is quite another matter to commercially produce filaments of the chosen materials. The greatest problem in the production of metallic filament incandescent lamps has been to produce the filament material in a high state of purity and in

the proper physical form, and the ingenuity of the manufacturer has been taxed to the utmost in devising means by which this can

FIG. 6.



be accomplished.[5] Incidentally it might be mentioned that largely through the continued effort of various investigators to produce

[5] The general equations by which the length and diameter of a filament of any given material, voltage, candlepower and efficiency can be calculated (provided that certain constants are obtained from a sample filament) are expressed below:

FILAMENT EQUATIONS.

d = Diameter of filament.
l = Length of filament.
R = Resistance of filament 1 mm. in diameter. 1 mm. in length at operating temperature.
S = Surface per watt.
V = Volts.
e = Watts per candle.
$cp.$ = Candlepower.

$$S = K_1 e^b \qquad R = K_2 e^a$$

$$d = K_1^{\frac{1}{3}} K_2^{\frac{1}{3}} e^{\frac{a+b+2}{3}} \pi^{-\frac{1}{3}} V^{-\frac{2}{3}} (cp.)^{\frac{1}{3}}$$

$$l = K_1^{\frac{2}{3}} K_2^{-\frac{1}{3}} e^{\frac{-a+2b+1}{3}} \pi^{-\frac{2}{3}} V^{\frac{2}{3}} (cp.)^{\frac{1}{3}}$$

filaments of refractory materials, the general knowledge of the metallurgy and chemistry of such metals as osmium, tungsten, molybdenum and tantalum has been advanced wonderfully within the last few years.

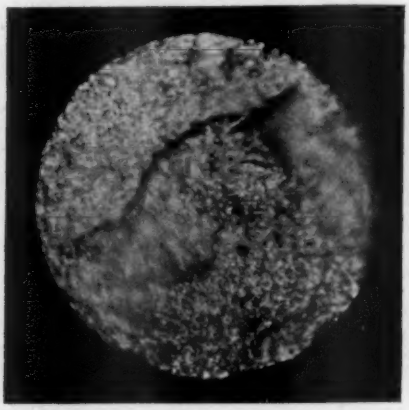
Tungsten filaments from 0.001 to .013 inch in diameter are required in lamps at present on the market. Filaments as small as 0.0008 inch can be made commercially and in an experimental way, filaments as small as 0.00068 inch have been produced. The latter filament is small enough to make a lamp of about 8 or 9 candlepower at 110 volts and at 1.25 w.p.c.

FIG. 7.

The mechanical difficulty of manufacturing such small filaments to exact and uniform dimensions is not the only one encountered in their production. The filaments must be of a uniformly high degree of purity, in order that the lamps will give good commercial service. It is difficult to secure a high degree of purity in tungsten metal, principally because its atomic weight is high and in consequence thereof a very little carbon (which is the most common impurity) is sufficient to form a considerable amount of tungsten carbide (probably W_2C), a compound which has altogether different physical properties than the metal itself. Tungsten carbide (W_2C) contains only 3.16

per cent. carbon by weight; 1 per cent. of carbon in tungsten metal would give about 31.6 per cent. of this tungsten carbide and would render the metal only 69.4 per cent. pure. Tungsten as it exists in the finished filaments of present commercial lamps probably contains less than 0.01 per cent. of combined carbon. The difficulties encountered in refining tungsten are very great, and it is only by the use of the greatest precautions that metal as pure as that required in commercial filaments can be secured. From this it may be seen that the amount of material actually contained in the filament of an ordinary tungsten lamp can give

FIG. 8.



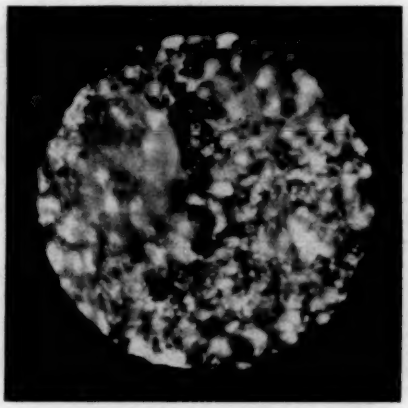
no adequate idea of the value of the filament as it exists in the slender thread of highest purity.

The examination of the filament of an incandescent lamp under the microscope reveals many interesting changes during the various processes of manufacture and during the subsequent burning. This applies particularly to the metal filaments.

The structure of the tungsten filaments may be best shown by microphotographs of the cross-sectional fracture. It is very difficult to get micrographs which will show distinctly this structure, due to the fact that all parts of the slightly irregular surface cannot be brought into sharp focus. In looking at the specimens under the microscope, where the focus can be gradually changed, the character of the surface can be seen to much

better advantage. For the purpose of illustrating the change in structure during one process of manufacture, micrographs of rather heavy filaments have been prepared since the large filaments show the change to somewhat better advantage. The filaments represented in the micrographs are about 0.008 inch in diameter, practically six times the diameter of a 40-watt 110-volt filament. The first micrograph (Fig. 6) illustrates the filament as pressed from a mixture of very finely divided metallic tungsten and a binding material. It has a dull black fracture which exhibits an extremely fine structure. Little visible change takes place in the filament during the firing and the first forming

FIG. 9.

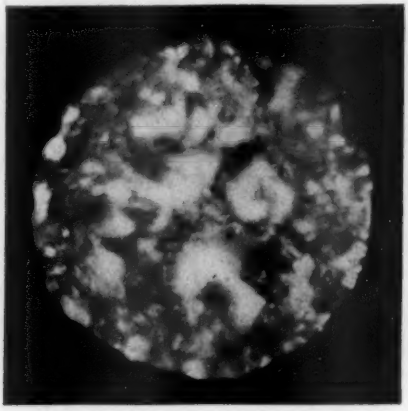


steps, as may be seen in Fig. 7. The black streak on this section does not indicate a crack but simply an uneveness in the broken surface. When the temperature reaches a certain point in the forming process a very sudden change takes place in the filament as Fig. 8 shows. The particles of tungsten have here drawn closely together and the binding material used in squirting has been practically eliminated. The reduction in diameter is about 20 per cent. and the fracture, previously dull black, is bright and metallic and shows a very fine structure. The effect of raising the temperature still higher is shown in Fig. 9. The fracture here shows a decidedly crystalline appearance. The crystals are small in size and are very uniformly distributed

over the cross-sectional surface. To carry the study a little further Fig. 10 shows the fracture of a filament which had been made up into a lamp and which had burned about 250 hours. Evidently in this case at least there is a tendency for the size of the grain to increase slightly with burning—particularly toward the centre of the filament. Reference will be made to this latter in connection with filament strengths.

Microscopic inspection of the longitudinal surface of tungsten filaments after various periods of operation show that a gradual wrinkling or breaking up of the surface takes place. Apparently the effect is confined almost entirely to the surface

FIG. 10.

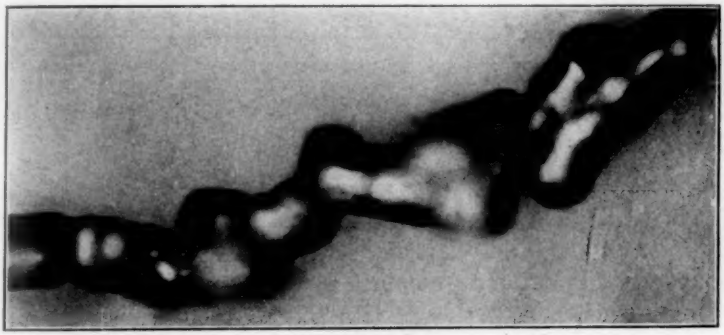


material, the filament itself suffers no serious distortion and no marked difference in appearance is produced by burning on alternating current. The appearance of the tantalum filament after burning on direct current is not very different than that of a tungsten filament but on alternating current, however, there is a remarkable difference. A gradual breaking up of the tantalum filament takes place and some rather extraordinary specimens are sometimes found as seen in the accompanying figure (Fig. 11). The breaking up of the tantalum filament on alternating current can hardly be ascribed to vibration due to rapid heating and cooling because tungsten filaments, operated under similar conditions do not show this tendency to "offset."

The study of the change in appearance of filaments throughout their life naturally leads to a consideration of the effect of burning on the strength of the filament. Before discussing this matter, however, a few remarks about mechanical strength in general may be interesting.

It is important that the lamps possess considerable strength so as to render the breakage from shocks as small as possible. The fragility of the metallic filament lamps has been a considerable handicap in competition with other types and were it not for this one thing, their superior economy, better candlepower maintenance and improved quality of light would have made their use much more general to-day.

FIG. 11.

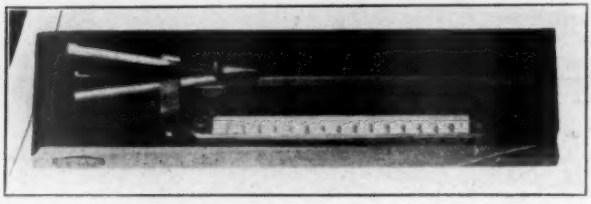


The ruggedness of an incandescent lamp depends upon two things: (1) the mechanical strength of the filament itself; (2) the method by which the filament is supported within the lamp. In order to investigate the relative strength of lamps of different types, various methods of testing them have been devised. Strength tests are made with the filaments cold because when they are heated it is practically impossible to break them, the most serious damage that can then result from shocks and blows being a twisting together of one or more loops.

One method of strength testing consists of mounting the lamp rigidly on a block which can be bumped by a second block allowed to swing as a pendulum. The impact is regulated by the arc through which the pendulum is allowed to swing and is

increased by small increments until the filament is ruptured. The method has been modified by one investigator so that the impact is obtained through a ball rolling down an inclined plane. Another method requires the lamp to be mounted on a block which can be dropped from gradually increasing heights, the apparatus resembling somewhat a miniature pile driver. Other tests have been made by packing lamps in boxes as for shipment, and dropping the boxes from increasing heights, the lamps being frequently inspected. These methods have the advantage of breaking the lamps under conditions at least approximated in service, and moreover give some indication as to the value of the method used in supporting the filament. The results obtained are at best somewhat erratic and a large number of lamps must

FIG. 12.



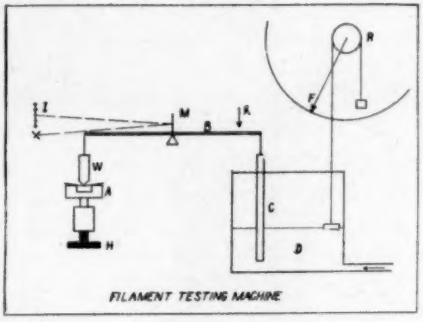
be averaged in order to obtain a proper appreciation of relative strengths.

In order to obtain some idea as to the strength of the filament itself, considered apart from its supporting structure, several methods of testing have been commonly used. One method consists in laying the filament on a pad of paper smooth but not rigid, and allowing a small metal cylinder to roll lengthwise along it. Rollers of increasing weights are used until the filament breaks. In another form of filament testing device shown in Fig. 12, the filament is drawn by a hook at the centre between two converging guides until it breaks, the distance which it was drawn into the " V " before breaking gives an arbitrary measure of its elasticity. This method has been varied in another device so as to draw the filament through a spiral guide, thus giving the sample a greater and greater curvature until it breaks. From the description of these methods it will be apparent that the strength could be measured in only an arbitrary way.

The number of ways in which filament strengths can be measured with precision is somewhat limited by the physical nature of the filaments and by their extremely small diameter. It is very probable that the elements of fatigue and ability to resist suddenly applied stress are important factors in determining filament strengths, but the difficulty of devising tests involving such elements makes it necessary to gauge the strength by some other means.

The filaments readily lend themselves to cross-bending tests and in order to carry out certain investigations, a device for making such tests with some degree of accuracy was constructed. To obtain the greatest amount of information from a cross-bending test it is desirable to measure not only the breaking

FIG. 13.



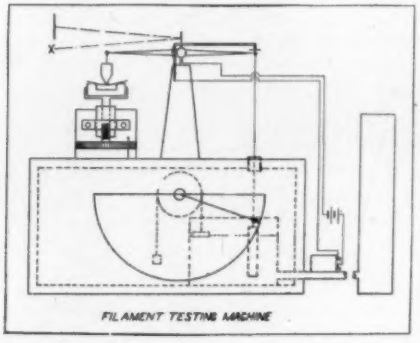
FILAMENT TESTING MACHINE

strength but the deflection as well. In the device mentioned, short pieces of filaments were supported at points 0.5 cm. apart and a load slowly applied at the middle until the filament broke, the load and deflection both being measured. By taking short pieces of filament it was possible to test from ten to twenty samples from a given lamp, and the average load and deflection given by these ten or twenty samples gives a very good measure of the filament strength in that particular lamp. In addition to determining the breaking strength, the deflection under various loads could be measured and deflection load diagrams could thus be obtained. Before discussing the results obtained in transverse bending tests a short description of the device with which the tests were made will be given, as it is believed that the application of the principle involved is new.

The machine (Fig. 13) consists essentially of a horizontal beam balanced on a knife edge, supporting at one end a cylindrical plunger (C) and at the other end a cylindrical weight (W) of the shape shown in the figure. The weight (W) at one end of the beam hangs with its lower edge midway between the points of support of the filament which is laid horizontally across an opening 0.5 cm. long. The block (A) carrying the filament can be raised through measured distances by means of a micrometer screw.

A small concave mirror (M) on the beam reflects light from the source to form an image at (I). By keeping this image on

FIG. 14.



a certain point, the beam may be kept horizontal and the deflection of the filament may be read from the micrometer screw.

The plunger at the other end of the beam hangs within a vessel which may be filled slowly with water. The plunger is buoyed up by the water as the latter rises and a load proportional to the weight of water displaced by the plunger is thrown upon the filament. As the plunger is uniform in section, the volume of water displaced can be most easily measured by its height upon the plunger. In testing, the beam has been kept balanced with a small part of the plunger submerged and consequently the load upon the filament is determined by a difference in water levels. To enable the water level to be read with accuracy, a carefully balanced float rides upon the surface of the water

in vessel D and by means of a silk thread passing over the small pulley R its motion is magnified by the long pointer F travelling over an arbitrary scale. The water level readings can be reduced to the equivalent load in grammes on the filament by means of a calibration curve.

After putting the filament in place, and taking the initial reading of the pointer F and the micrometer head H water is allowed to flow into the vessel D. As this throws a load on the filament and produces a deflection, the operator raises the filament with the micrometer screw, in order to keep the image I at a fixed point. The loading continues until the filament breaks, at which instant the water supply is automatically cut off by electrical contact of the unbalanced beam with the point K. The pointer F indicates the water level at breaking and from the calibration curve the breaking weight can be expressed in grammes. The deflection of breaking is indicated by the difference between the initial and final readings of the micrometer head.

A more detailed drawing of this testing device which illustrates the general arrangement of parts is shown in Fig. 14.

In order to compare strengths and deflections of filaments of varying size, it was necessary to express the results in terms of some unit length and diameter. Consequently all measurements of strength and deflection have been reduced to the equivalent load in grammes and deflection in cm. of a filament 0.5 cm. long and 0.005 cm. in diameter. To perform this reduction, it was necessary to know the diameter of the test-pieces, and as the diameter of the filaments tested was about 0.004 cm. (1.4 mils) an optical micrometer was used. Individual readings of diameter could be checked within about 2 per cent.

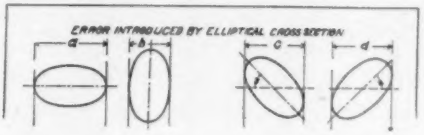
In some cases filaments were found to be slightly elliptical in cross section rather than circular. The difference between the maximum and minimum diameter, however, rarely exceeded 10 per cent. In reducing the results of the cross-bending tests to a common basis, the diameter of the filament was therefore taken as the mean of two diameters at right angles in order to reduce the error due to possible deviation from a circular section. It can be shown where such deviation is small (10 per cent. or less), any two projected diameters at right angles

will give the same average within small limits of error,[6] and further that the percentage error in strength introduced by considering the mean of two such diameters as the diameter of an equivalent circular section, is approximately one-half of the percentage difference between the maximum diameters.[7]

Some of the most interesting tests made with the device just described have reference to the change in strength of the fila-

---

[6] Showing average by using any two projected diameters.



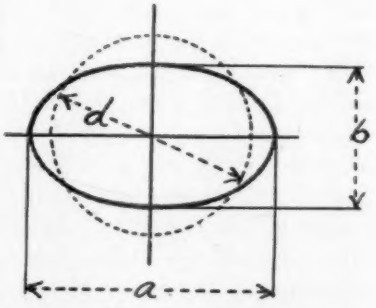
Ave. Dia. $D_1 = \frac{a+b}{2}$ Ave. Dia. $D_2 = \frac{c+d}{2}$

$(D_1 - D_2)$ is a maximum when $c = d$.

Ratio $\frac{b}{a}$	Deviation $\frac{D_1 - D_2}{D_1}$
1.0	0.00 per cent.
0.9	0.31 per cent.
0.8	0.55 per cent.

[7] Assuming a filament of elliptical section, let a = maximum diam.; b = min. diam.; and $d = \frac{a+b}{2}$. Strength of circular section varies as d^3. Strength of elliptical section varies as ab^3.

If $a = 1.1$
and $b = 1.0$
$d = 1.05$
$d^3 = 1.1576$
$ab^3 = 1.1 \times 1.0^3 = 1.1000$



A circular section is about 5.2 per cent. stronger than an elliptical section of same mean diameter when the maximum diameter of the ellipse is 10 per cent. greater than the minimum. It is assumed that the filament having the elliptical section would break in the weakest direction.

ment during its life. Three lots of 40-watt 110-volt tungsten-filament lamps representing modifications in manufacturing processes were run through such comparative test. These lots may be designated as *A, B* and *C*. Special care was used in order to have the filaments in the lamps of each lot very uniform. Each lot was divided into two parts, one of which was burned on 60-cycle alternating current and the other on direct current. All lamps were burned at 1.23 w.p.c. At certain intervals lamps of each lot were removed from the burning racks and the strength of the filaments tested. The results of these tests can best be shown graphically in Figs. 15, 16 and 17.

FIG. 15.

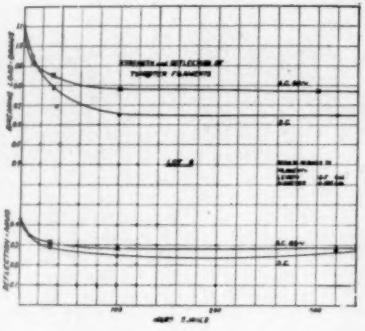
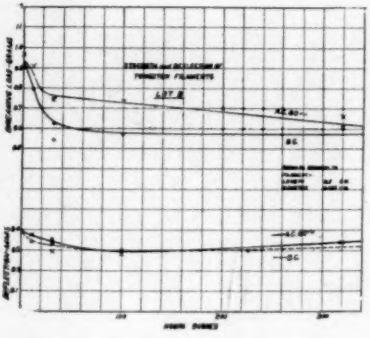


FIG. 16.

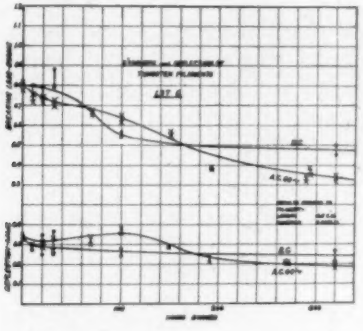


The change in strength and deflection with burning is shown for lamps of each the three individual lots operated on both alternating and direct current for periods up to 320 hours. While each curve has been determined from the test of relatively few lamps, the general tendency of the curves is about the same in each case. Each point on the curves is the average of 10 determinations of strength of the filament from a single lamp. In lot *C* (Fig. 17) the probable error of each average is shown by plotting a vertical line rather than a point and this serves to give some idea of the uniformity of the data obtained from individual lamps. The deflection at breaking indicates that the flexibility of the filaments does not change very much with burning, especially after the first few hours.

The decrease in strength with burning could be most easily shown by either some change in the structure of the filament or

by some change in the effective cross section. Although the results have all been reduced to terms of a uniform gross diameter, a microscopic inspection of the filament shows that there is a tendency for the surface to become wrinkled with burning which would, in all probability tend to reduce the effective diameter as far as strength is concerned. Since the breaking strength varies directly as the cube of the diameter, a reduction of 15 per cent. in this dimension would be sufficient to account for a reduction of 40 per cent. in strength. The filaments represented in the strength tests show that in general the surface which was originally smooth gradually becomes rough during the first 100 hours burning. Beyond this point the changes are not so

FIG. 17.

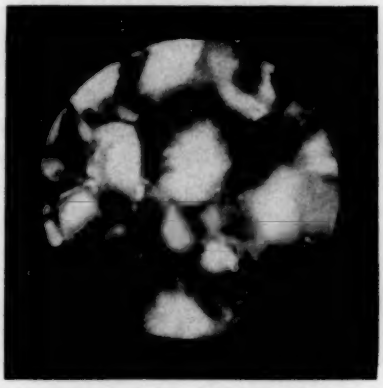


marked. The strength curves indicate in a general way that the greatest reduction in strength occurs, during the first one hundred hours of operation, and thereafter the change is less marked. This seems to point to the possibility that the strength is dependent at least to some extent upon the surface roughening. It might be noted that during the period covered by the test the gross diameter of the filaments of the several lots remain practically constant, *i.e.*, no marked reduction in diameter with burning could be noted.

In regard to changes in structure the cross sections of the large filaments previously shown indicate that there is a tendency for the crystalline structure to become somewhat coarser with burning. This change would naturally tend to weaken the filament due to the greater ease with which the fracture could

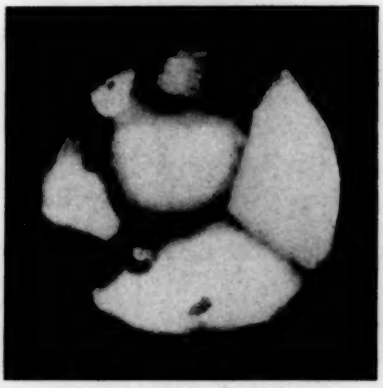
follow the larger crystalline surfaces. From an inspection of the cross section of the filaments represented in the strength tests it was found that lot *A* possessed in practically every case

FIG. 18.



a very compact crystalline structure, while lot *C*, which gave the least mechanical strength, showed in many cases a mixed structure, *i.e.*, partly crystalline and partly smooth, slightly

FIG. 19.



rounding surfaces resembling somewhat the appearance of certain large filaments, as shown in Figs. 18 and 19. Evidently the structure giving such smooth surfaces tended to decrease

the resistance to fracture. A compact small-grained crystalline structure is apparently the more desirable from the stand-point of strength. The investigation, however, should be carried further before any definite conclusions are reached.

In order to give the relative idea of the strength and stiffness of a tungsten filament and a glass thread, a glass rod was drawn down to a diameter approximately equal to that of the filaments and a number of samples were tested. The ultimate strength of the threads of glass was almost three times that of the filament (which was one of lot *A* burned 32 hours on D.C.), but the flexibility of the glass was considerably less, giving about 60 per cent. as great a deflection as a tungsten filament under the same load.

The Sterilization of Water by Chlorine and Ozone. G. SIMS WOODHEAD. (*Surveyor,* xxxviii, 114.)—About 1,000,000 gallons per day of the water supply of Cambridge, Eng., was treated with a solution of bleaching powder. One part of available chlorine per 7,000,000 to 8,000,000 parts of water completely destroyed non-sporing organisms within 20 minutes and left no taste nor smell of chlorine. The proper amount of "bleach" was gauged by tests of the treated water after contact with potassium iodide and starch. The test should give a violet color to the water; a deep blue color shows too much "bleach" has been used. If the right amount is used it is unnecessary to neutralize any excess of chlorine with sodium bisulphite. The same water was freed from *B. coli* by ozonization with the Siemens-Halske apparatus. Although this process is not so simple and is more expensive than the chlorination process, it has advantages from an æsthetic point of view. In experiments carried out with ultra-violet rays, sterilization was effected at once.

A New Radiation Pyrometer. ANON. (*Amer. Mach.,* xxxiii, 1036.)—The Brown Instrument Co. of Philadelphia has recently brought out a new pyrometer of the fixed-focus type. This pyrometer has a finder somewhat similar to those used on kodaks which has been placed on the tube, and by means of this, the tube can be readily pointed directly at the furnace opening. It also acts as a measure of distance, and it is only necessary that the bright red of the furnace opening takes up the whole view in the finder. If some of the dark outside wall of the furnace is showing around the bright red opening, the tube is too far distant, and should be moved closer, until only the bright red is showing. The instrument is accurate under ordinary working conditions within 1 per cent., or 30° at 3000° F.

THE PREPARATION AND TESTING OF DRUGS.*

BY

WILLIAM A. PEARSON, Ph.C., Ph.D.,

Professor of Chemistry and Toxicology in the Hahnemann Medical College of Philadelphia; Chemist to Smith, Kline and French Company.

DRUGS may be defined as substances which are used for the prevention or alleviation of disease. Logically they fall into three great divisions:

1. Medicinal chemicals.
2. Preparations made from plants.
3. Biological products.

MEDICINAL CHEMICALS.

The quantity of chemicals used for medical purposes is very small, compared to the quantity which finds technical application. On this account manufacturing chemists will not strive to prepare chemicals especially for pharmaceutic use. Moreover, scientific methods and elaborate processes have made possible the manufacture for technical use of acids and salts which are sufficiently pure for medicinal purposes, as a rule. It is proper and logical that the great chemical industries with their knowledge, equipment, and experience should prepare medicinal chemicals, although the degree of purity of these compounds is governed to a great extent by their technical use. Thus magnesium sulphate (Epsom salt) is used extensively in medicine, but to a far greater extent in the leather industry. The commercial product is quite pure, but usually contains from one-tenth to three-tenths of 1 per cent. of magnesium chloride, which does not interfere to an appreciable extent with the medicinal properties of the sulphate, yet is responsible, to a large extent, for the bitter taste of the latter. The magnesium chloride can be removed at an additional expense, however the public desires the commercial product, as is shown by the protest against paying the higher price for the purer article. In another case the keen

* Presented at a Stated Meeting of the Section of Physics and Chemistry, held Thursday, January 5, 1911.

rivalry in the baking powder industry, and the consequent improvements in the manufacture of potassium bitartrate (cream of tartar) have made possible the production of that salt about 99.98 per cent. pure, on a commercial scale at a low cost. There is no reason why any of the chemicals used in medicine cannot be purified to the same degree, with the same expenditure of labor. However, this is unnecessary in the majority of cases, since the small amount of impurity is often innocuous.

When pharmacology and physiological chemistry determine the exact relation between physiological action and chemical constitution, chemical industry may be depended upon to prepare almost any desired compound, however intricate. The development of therapeutics will be along this line, thus dioxydiamidoarsenobenzol was deliberately planned and prepared.

Since the preparation of medicinal chemicals is so intimately related to the world's great chemical industries, any attempt to describe the manufacture of these compounds would require more time than is available this evening. Two extensive establishments may be chosen as representative, one in Darmstadt, Germany, the other in our own city; both are engaged extensively in the manufacture of medicinal chemicals, although other establishments also occupy important positions in the preparation of this class of pharmaceuticals. The house of Merck in Darmstadt has been in business for approximately two hundred and fifty years, and prepares almost every chemical compound used in medicine. The Powers-Weightman-Rosengarten Company was formed by the consolidation of two large corporations, both of which were established nearly a century ago, and have contributed largely toward making Philadelphia the centre of pharmaceutical activity of this continent.

PREPARATIONS MADE FROM PLANTS.

Medical preparations made from plants are usually classified as "straight pharmaceuticals"; this designation is applied particularly to those preparations known as fluid extracts, extracts, tinctures, pills, tablets, tablet triturates, capsules, elixirs, emulsions, ointments, etc. Brief definitions of these terms may be given.

Fluid extracts are liquid preparations of such strength that one cubic centimetre of the liquid contains the active principles of one gramme of the drug.

Extracts may be considered a fluid extract concentrated by evaporation, and may be in a plastic condition or in the form of a powder. Whenever heat exerts a destructive action upon the active principles, the evaporation is conducted in vacuum.

Tinctures are similar to fluid extracts, but usually are one-tenth as strong as the latter.

Fluid extracts and tinctures are prepared by means of an apparatus called a percolator, which is a tubular container with a small opening at the bottom. The ground drug is placed in the percolator and the active principle is extracted by permitting a suitable solvent to seap through it. The size and shape of the percolator, the menstruum used, the fineness of the powder to which the crude drug previously has been ground, and the rate of flow of the solvent depend upon the properties of each drug.

Tablets are compressed by machines, some of which have a capacity of 500 tablets per minute. The material to be compressed must be granulated so that it will feed uniformly in the machine and hold together properly after being compressed. Moreover, the tablets must be so prepared that they will disintegrate properly when used.

Some confusion exists concerning the distinction between a tablet and a tablet triturate. Tablet triturates are made by gently pressing a moist powder into moulds which hold from 25 to 1000, allowing to dry and then removing from the mould.

The gelatin capsule industry is confined to a few large establishments, where the capsules are prepared by elaborate machinery in enormous quantities. The hard capsules are made by dipping brass pins into the melted gelatin, drying, cutting away the excess of gelatin and fitting on the caps, which are made in the same way but are slightly larger. The proper consistency of the gelatin plays an important rôle in the manufacture of capsules. It is interesting to note that there are at least two different successful machines on the market, which remove the caps from the empty capsules, fill the capsules and adjust the caps again; the machine is able to fill 50,000 capsules per hour.

In the manufacture of soft capsules and globules, a layer of the medicament is placed between two layers of gelatin, and the entire mass is subjected to pressure between the upper and lower dies of a press.

Pills are made by a special machine, direct from the plastic mass. This machine first rolls the mass into a long, thin cylinder,

then cuts this into a number of smaller cylinders, and finally rolls each small cylinder into a pill. The machine will prepare from 50,000 to 500,000 pills in a day of ten hours. In the preparation of the plastic mass certain problems arise, it must have a certain consistency and remain soluble, moreover the medicinal constituents must be evenly distributed throughout the entire mass.

"Friable" pills are manufactured from a moist nucleus by adding successive layers of powder, just as a snowball is increased in size by rolling over the snow.

Crude drugs for the preparation of homœopathic medicines are usually imported, packed in alcohol; from them tinctures, tablet triturates and other preparations are manufactured. The largest manufacturers of homœopathic medicines are located in Philadelphia.

BIOLOGICAL PRODUCTS.

These products are made either directly or indirectly from pathogenic (disease-producing) microörganisms. They are of two general types—the Antitoxins and the Vaccines.

In the preparation of antitoxins, animals are rendered immune to the toxins or poisons produced by the microörganisms in their development, and the blood-serum of these immunized animals is used for combating the corresponding disease. Satisfactory antitoxins have been prepared for only diphtheria and tetanus, although they are considered of value in some few other infectious diseases. In both diphtheria and tetanus, the toxin or poison, given off during the development of *Bacillus diphtheriæ* and *Bacillus tetani* respectively, is responsible for the alarming symptoms and death caused by these diseases. The antitoxins actually neutralize these toxins and the patient usually recovers. The details of the manufacture of antitoxins are too intricate to permit a full description of the technic.

Vaccines are attenuated (stunted) cultures of pathogenic microörganisms. Their efficiency depends upon the fact that they produce a mild attack of the disease, which results in subsequent immunity to the disease. Smallpox vaccine is the best known vaccine; it is allowed to develop upon the belly of young heifers, since no suitable artificial medium has yet been discovered.

The bacterial vaccines are prepared in various ways from cultures of microörganisms on artificial media; in some cases

they have been used with success as diagnostic and curative agents.

Future progress in therapeutics will no doubt be made largely through the agency of bacterial vaccines and other biological products.

THE RELATION OF THE MANUFACTURER, WHOLESALER, AND RETAILER TO EACH OTHER.

The large manufacturer of drugs has certain advantages over the retail pharmacist in the preparation of pharmaceutical products. The manufacturer is able to prepare the finished drug far more economically than the retailer. A concrete example may be given of the decrease in price of a pharmaceutical product as the result of its manufacture on a large scale. According to Jacob Dunton, the pioneer tablet manufacturer, one hundred quinine tablets were sold for four and one-half dollars in the year 1877; to-day the same number of tablets may be purchased for a few cents.

The manufacturer is able to purchase crude drugs in large quantities and has the facilities for preparing from them enormous quantities of the finished product, lastly and most important he can assay and standardize a large quantity of the final product with the same expenditure of time and labor as the retailer must expend in testing a small quantity of his own preparation; hence greater uniformity and reliability are to be expected in the product of the manufacturer. However, on the whole, the retail pharmacist manufactures from the crude drug an enormous quantity of medicines, including aromatic waters, infusions, solutions, prescriptions, and such preparations as are dispensed extemporaneously. This practice is to be encouraged.

All the large drug laboratories have been developed since 1860. Certain of the products of each manufacturer were received with greater favor than the same preparations of other manufacturers, either because of superiority, price or other reasons. As other manufacturers entered the field, competition became keener and to a large extent the profits were eliminated on those preparations in which competition was greatest. In this state of affairs each manufacturer increased his attention to those products of his plant for which the demand was greatest, and thus made a specialty of those products. Thus one firm

specializes in the preparation of elixirs, another in the manufacture of ether for anæsthesia; other firms devote their attention to dental pharmaceuticals, capsules, medicines for domestic animals, insecticides, fungicides, and other special lines.

The increase in number of manufacturing laboratories and the consequent increase in competition exerted an influence on the wholesale druggist. The newer manufacturers experienced difficulty in disposing of their preparations through the wholesaler, and therefore sold directly to those retail dealers who transacted sufficient business to warrant the purchase of drugs in large quantities. As a result the business of the wholesalers decreased in volume and they were unable to purchase from the older manufacturers to such an extent as formerly. Thereupon the older manufacturers also began to sell directly to the retailers with consequent loss to the wholesalers. In order to retain the prestige of their patrons, the wholesalers began the manufacture of pharmaceutical and medicinal preparations.

THE DRUG TRADE OF THE UNITED STATES.

The following data will convey an idea of the magnitude of the drug trade of the United States:

Philadelphia has always played a leading rôle in pharmaceutical progress, as has already been described by Dr. Lowe in his paper on "Pharmacy in Philadelphia," which was published in the *Pharmaceutical Era* for 1908. A number of large manufacturing druggists are located in Philadelphia, others are to be found in Baltimore, Brooklyn, and the northern portion of the Middle West, *e.g.*, in Detroit, Chicago, and Indianapolis. The business transacted by these manufacturers, at home and abroad, is enormous; for instance, a single manufacturer employs three hundred and sixty travelling salesmen. Several of the manufacturing druggists maintain branch laboratories in Canada and one firm has such a laboratory in England. The foreign trade is quite extensive, extending even to Latin America and Australasia. The large wholesale druggists likewise are located in the Middle Atlantic and Northern Central States, especially in the cities of Philadelphia, New York, Chicago, St. Paul, and St. Louis. The total annual sales of five of the more prominent manufacturing laboratories amounts to eighteen million dollars, a sum but slightly below the tax levy of 1908 in Philadelphia. The total

annual sales of three of the larger wholesale druggists amounts to fifteen and one-half million dollars, which is about one and one-half times the expenditure for public schools in Philadelphia for the year 1908.

RESEARCH WORK.

The public in general and the physician in particular are deeply indebted to the manufacturers of pharmaceutical products on account of the extensive, systematic researches which are made by all the larger establishments; these researches lead directly to marked advances in therapeutics and medication. The manufacturer is better prepared to solve the many problems of modern medicine than either the retail pharmacist or the practicing physician. Of course, the manufacturer directly reaps some benefit from these researches—he deserves it—but all information not closely related to methods of manufacture is given freely to the medical profession.

Old products are improved and new ones conceived, prepared and standardized. After complete chemical, physiological, and clinical tests have been made, the medical profession is given the benefit of this work. Large research laboratories have been erected by the manufacturing druggists; in America, those situated in Philadelphia, Detroit, and Indianapolis deserve special mention for the excellence of the work which has been carried out within their walls. In addition to the experimental work in the manufacture of pharmaceutical preparations, researches are also being made in pharmacology, pathology, and chemistry in these laboratories.

The day is not far distant when the manufacturers will raise their own drugs. For several years belladonna has been grown with success for the manufacture of plasters. The cultivated drug has not proved inferior to the wild drug and is probably superior to the latter in its alkaloidal content.

If a better conception of the pharmaceutical industry has been given to the members of the Franklin Institute, my purpose has been accomplished.

[During the lecture a number of lantern slides were shown, depicting various pharmaceutical laboratories, and the manufacture and testing of drugs therein. Information was given as to the capital, yearly sales and special preparations of each laboratory.]

FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting, held Wednesday, March* 15, 1911.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, March 15, 1911.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership since last report, 3.

The resolution from the Board of Managers recommending General James Allen, Chief Signal Officer, U. S. Army, for honorary membership was adopted.

The Chairman then introduced Prof. George W. Ritchey, of the Mt. Wilson Solar Observatory, Pasadena, California, who delivered an interesting address on "Recent Astronomical Photography."

The speaker described the construction of refracting and reflecting telescopes and the equipment of large astronomical observatories, referring especially to those of the Mt. Wilson Observatory. He presented illustrations of the instruments of this observatory and their housing; views were shown of the surrounding country and the obstacles which were encountered in transporting the various parts of the apparatus over roads especially constructed, to the top of the mountain.

Lantern slides were shown of the workshop in which glasses of sixty and one hundred inches are being ground for the reflecting telescopes.

Remarkable photographs of star clusters and nebulæ were exhibited during the course of the lecture.

The thanks of the meeting were extended to Dr. Ritchey and his interesting address was referred to the Committee on Publications. Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting, held Wednesday, March* 1, 1911.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 1, 1911.

DR. GEORGE A. HOADLEY *in the Chair.*

The following reports were presented for final action:

No. 2455.—Hardinge Conical Ball and Pebble Mill. (Referred back to subcommittee.)

No. 2461.—Shore Scleroscope (Hardness Testing Apparatus). (Scott Medal.) Adopted.

No. 2476.—Roper Safety Propeller. (Referred back to subcommittee.)

No. 3489.—Hopkins' Speedometer and Dynamometer. (Longstreth Medal.) Adopted.

The following report was presented for first reading:

No. 2469.—Crisfield Moisture Determinator for Coke, etc. (Referred back to subcommittee.)

R. B. OWENS,
Secretary.

SECTIONS.

Mechanical and Engineering Section.—A meeting of the Section was held on Thursday, February 23, 1911, at 8 o'clock, P.M. In the absence of the regular officers of the Section the meeting was called to order by Dr. Owens, Secretary of the Institute; 40 members and visitors were present.

An invitation was extended to those present to attend the lecture by Dr. L. H. Bailey of Cornell University at the Harrison Laboratory of Chemistry, University of Pennsylvania, on the evening of February 27th, under the auspices of the Pennsylvania Chapter of the Society of the Sigma Xi.

The Chairman then introduced Mr. Henry G. Brinckerhoff, of Boston, who presented a communication on natural and artificial draft.

The problem of draft and its proper application in power plants was given full consideration. Suggestions were made as to the height and area of chimneys and their location, and various methods and apparatus for induced and forced draft were described and illustrated by means of lantern slides.

A brief discussion followed the paper, in which the Chairman, Messrs. Crisfield, Gartley, Parker and others participated.

On motion duly seconded, the thanks of the meeting were extended to the speaker. Adjourned.

ALFRED RIGLING,
Acting Secretary.

Joint Meeting of the Electrical Section of the Franklin Institute and the Philadelphia Section of the American Institute of Electrical Engineers.

The first joint meeting of the above sections was held on Thursday evening, March 2d at eight o'clock in the hall of the Institute.

Mr. W. C. Eglin and Mr. Chas. F. Young acted as joint Chairmen of the meeting; 360 members and visitors were present. Mr. Young called the meeting to order and congratulated the members of the two societies on the successful beginning of their coöperative work. He then introduced Dr. Chas. Proteus Steinmetz of Schenectady, N. Y., who addressed the meeting on "Some Unexplored Electric Fields." He reviewed the progress of electrical investigation and referred to the theories which had been proven to be incorrect, or about which there is still considerable speculation.

Among the subjects given consideration were certain electrostatic phenomena including lightning, the resistance to the flow of alternating current in trolley rails, some unexplained phenomena of magnetism, the conduction of current in gases, the arc, etc.

He also called attention to the so-called electric fishes and the descriptions given of them in the works on natural history and stated that there was some mystery in this case, as it is inconceivable that they could develop, even momentarily, some hundreds of kilowatts of electric power.

In the discussion following the reading of the paper, Dr. Hoadley, Messrs. Snook, Calvert, Hixon, and a number of others participated.

A vote of thanks was extended to Dr. Steinmetz and the meeting then adjourned.

R. B. OWENS,
Secretary.

Section of Photography and Microscopy.—A meeting of the Section was held on Thursday evening, March 9th, at eight o'clock; 45 members and visitors were present.

The meeting was called to order by Dr. Henry Leffmann, Chairman of the Section, and in the absence of the Secretary the reading of the minutes was dispensed with.

The communication of the evening on "Some Unusual Photographic Processes" was presented by the Chairman.

The speaker described numerous peculiar processes including the several methods for producing photographs in colors. The subject was illustrated by many lantern slides of unusual interest.

A specimen of carbon photograph on canvas was exhibited by Mr. Chas. Truscott, and slides of crystals of various chemicals and recent examples of photographs in colors were shown by others present.

ALFRED RIGLING,
Acting Secretary.

Mechanical and Engineering Section.—A meeting of the Section was held on Thursday evening, March 16th at eight o'clock. In the absence of the Chairman the meeting was called to order by Dr. R. B. Owens, Secretary of the Institute. Sixty members and visitors were present.

After the reading and approval of the minutes of the previous meeting the Chairman introduced Dr. Allerton S. Cushman, Director of the Institute of Industrial Research, Washington, D. C., who presented an interesting communication on the "Conservation of Iron."

The speaker presented interesting facts and statistics on the uses of iron and its destruction by rust, electrolysis and other means. Lantern slides illustrating the effects of salts and acids on iron, the formation of rust, the protective qualities of zinc and other related subjects were shown.

In the discussion which followed the reading of the paper Messrs. Colvin, Crisfield, Head and others participated.

A vote of thanks was tendered Dr. Cushman and his paper was referred to the Committee on Publications.

ALFRED RIGLING,
Acting Secretary.

MEMBERSHIP NOTES.

Elections to Membership.

RESIDENT.

MR. J. P. MAGILL, Care Fayette B. Plumb, Inc., Frankford, Philadelphia.
MR. JACOB G. BISWANGER, 1619 North Sixteenth St., Philadelphia.

NON-RESIDENT.

MR. H. P. TYSON, Collegeville, Pennsylvania.

Changes of Address.

MR. CHARLES A. SIMS, 2704 Cathedral Ave., Washington, D. C.
MR. JAMES S. WHITNEY, 206 Weightman Bldg., Philadelphia.
MR. H. M. BUSH, 508 Capitol Trust Bldg., Columbus, Ohio.

NECROLOGY.

Mr. James Elverson, *The Philadelphia Inquirer,* Philadelphia.

Mr. Elverson was born in England in 1838. He came to the United States in 1847 with his parents and was educated in the schools of Newark, N. J. He was one of the founders of the *Saturday Night,* and in 1880 established *Golden Days,* a weekly publication. Since 1879 he has been proprietor and publisher of *The Philadelphia Inquirer.*

LIBRARY NOTES.

Purchases.

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Gifts.

Pennsylvania Topographic and Geologic Survey Commission Report No. 1, Harrisburgh, 1910. (From Mr. E. V. d'Invilliers.)
American Society of Mechanical Engineers, Yearbook for 1911. New York, 1911. (From the Society.)
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New York State Education Department—91st Annual Report of the State Library, 1908. Parts 1 to 3 and Yearbook of Legislation, vol. 10, 1908. Albany, 1910. (From the State Library.)

Vermont State Documents, Sixth Biennial Report of the State Highway Commissioner 1909–10; Forty-first School Report 1910; Annual Report of the Banking Commissioner 1910; Legislative Directory, Biennial Session 1910; Seventh Biennial Report of the State Geologist 1909–1910; Vermont State Documents, 1909–1910. Montpelier, 1910. (From the State Library.)

CORRESPONDENCE.

ASHEVILLE, N. C., Jan. 20, 1911.

JOURNAL OF THE FRANKLIN INSTITUTE:

Some years ago, about 1880, there was published in your JOURNAL by myself, "Mechanics of the Flight of the Bird." . . . .

I have given the subject some thought since that "long ago" and now that the public is so thoroughly aroused at the wonderful achievements of aerial navigation, I am persuaded to revive and enlarge upon the subject. The article is indexed in my name.

Yours truly,

A. C. CAMPBELL.

Jan. 27, 1911.

(From the Editor to Mr. Campbell.)

. . . We take pleasure in sending you under separate cover a copy of the June issue 1881, of the JOURNAL OF THE FRANKLIN INSTITUTE containing your article on "The Flight of Birds." . . . If you finally decide to revise the article and bring it up to date, we should be glad to have you send us the manuscript, if you feel disposed to do so, in order that we may submit it to our Committee on Publications with a view to having it form a supplement to the original communication.

ASHEVILLE, N. C., Feb. 6, 1911.

THE EDITOR,

THE JOURNAL OF THE FRANKLIN INSTITUTE:

I received your letter of the 27th Jan., also the June issue of the 1881 JOURNAL OF THE FRANKLIN INSTITUTE which was a great surprise to me, and gives me much pleasure. I do not find, however, that I can make any improvement by revising the article. It is correct as far as it goes, and is thoroughly up-to-date. To enlarge upon the various principles, I fear, would put it out of favor for publication in any periodical.

I have long entertained the idea of putting into practice the principle of impact of air, in mechanical flight, and am quite sure that successful navigation will in the future result from this principle, rightly applied. On the other hand, many of the sad accidents are due, no doubt, to treacherous impulses of air, that come unawares, like the death dealing bullet from the gun, "Didn't know the thing was loaded." We should be able to carry a greater burden with diminished power, when the principles of impact of air are embodied in an aeroplane more nearly akin to the bird, since we know that mechanical principles practice no favoritism.

My attention was caused to revert to my publication of thirty years ago by reading the late popular periodicals, particularly the *Cosmopolitan*, February 1911, "The Wonderful New World Ahead of Us," by Thomas

A. Edison, pages 297 and 298. He seems to have fallen heir to my ideas, has rejuvenated them and put them on dress parade, in these times when antiquities are much in favor. I believe Mr. Edison is wrong, however, in his conclusions on how the buzzard soars. Soaring has never yet been proven; mathematically, mechanically, or demonstrated experimentally. The problem remains for future study, followed by experimental research looking to actual sustaining flight by aid of *wind*. I believe that it is generally conceded that the bird cannot soar except by aid of wind; else perpetual motion would be possible. Hence I venture to assert that Mr. Edison's sound waves come only as an *effect* of a force of air that gives the buoyancy, similar to the rhythmical impulses of the Rife hydraulic ram.

It shall be my pleasure to take up this problem in the immediate future, feeling that it is not so difficult as it seems; since all mechanical energy may be diverted into various channels, just as curvilinier motion may be changed to rectilinier motion, and the two factors of a given energy, mass and velocity, being infinitely variable.

I should be glad to encourage others to participate in the strife for an early solution of the problem, "The Mechanics of the Flight of Birds"—to the public.

Yours truly,

A. C. CAMPBELL.

BOOK NOTICES.

SMOLEY'S TABLES. Parallel Tables of Logarithms and Squares; Angles and Logarithmic Functions Corresponding to Given Bevels; Five Decimal Lotharithmic-Trigonometric Tables; Natural Trigonometric Functions Including Secant and Cosecant; Squares, Cubes, Square Roots, etc. By Constantine Smoley, C. E., Assoc. M.A.S.C.E., Principal School of Civil Engineering, I.C.S. Schools, xi + 503 pages, 7 x 4½ inches, flexible morocco. Sixth edition, revised and enlarged. Price $3.50 net. The Engineering News Publishing Company, New York, 1911.

One of the most frequent computations a designer of framed structures is called upon to perform is that involved in the solution of a right triangle. How irksome this is without the assistance of special devices, those who have much of such work to do, only too well know. Smoley's Tables are primarily intended to lighten this labor. Parallel tables of squares and their logarithms are given for each one thirty-second of an inch to fifty feet, and for each one sixteenth from fifty feet to one hundred feet. The logarithms and other tables that follow are additions to recent editions. That the tables have proved their value by extended adoption is attested by the issue of six editions since the first appearance in 1901. The work appears to contain every table the structural or mechanical designer is likely to need, with perhaps one exception,—a table of circular arcs expressed in radians. Such a table occupies only one page and its usefulness is many fold the space it occupies.

MOTION STUDY. A Method for Increasing the Efficiency of the Workman. By Frank B. Gilbreth, Member Am. Soc. Mech. Engineers, with an Introduction by Robert Thurston Kent, Editor Industrial Engineering. xiii + 116 pages, 8 x 5½ inches, cloth with 44 illustrations. Price $2.00 net. D. Van Nostrand Company, New York, 1911.

In modern manufacturing the various operations necessary in producing a large number of duplicates of an article are subdivided, classified and systematized to the greatest nicety with a view to increasing the output and economy of production. Such a mode of procedure is comparatively common, and at the present day excites little comment. In the development of a system of economic production, the sequence as well as the means of performing the required operations is the subject of close analysis.

Motion study is a somewhat similar system of even more minutely investigating the operations for the production of a required result. Not alone are the mechanical features of manual operations analyzed but physiological and psychological influences as well are considered. In short the aim is to study every feature affecting the movement of the hands and body with the object of simplifying such movements or reducing their number, and so decreasing the effort of performing a given operation. The author being identified with building operations on a large scale, has applied the study to bricklaying with most favorable results, the account of which serves as a concrete example of what may be accomplished by an analysis of this kind. Motion study has undoubtedly received prior attention resulting in increased output and improvement in quality, but such investigations have related more to materials and machines rather than to the personal characteristics of the individual operative. In that field the author appears to have broken new ground, and opened a region of research that may prove of the greatest value alike to the workman and the employer.

PUBLICATIONS RECEIVED.

U. S. Department of Commerce and Labor, Bureau of the Census. Cane and beet sugar. Summary of results of the census in 1909. 6 pages, 8vo. Washington, Government Printing Office, 1911.

U. S. Department of Commerce and Labor Results of Observations Made at the Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland, 1907 and 1908. By Daniel L. Hazard, computer, division of terrestrial magnetism. 93 pages, plates 4to. Washington, Government Printing Office, 1911.

Russia and the American Passport. Address by Louis Marshall of the New York bar to the delegates at the twenty-second Council Union of American-Hebrew Congregations, Thursday, January 19, 1911, together with resolutions unanimously adopted. 16 pages, 8vo. New York, American-Jewish Committee, 1911.

Canada Department of Mines. Bulletin No. 4, 2nd edition. Investigation of the peat bogs, and peat industry of Canada during the season 1909–10. By Aleph Anrep, Jr., peat expert. To which is appended Mr. Alf Larsen's paper on Dr. M. Ekenberg's wet-carbonizing process; from Teknisk Tidskrift, No. 12, December 26, 1908. Translated by Mr. A. Anrep, Jr., also a translation of Lieut. Ekelund's pamphlet entitled, A Solution of the Peat Problem, 1909; describing the Ekelund process for the manufacture of peat powder. By Harold A. Leverin, Ch. E. 44 pages, illustrations, maps, 8vo. Ottawa, Government Printing Bureau, 1910.

Canada Department of Mines. Bulletin No. 5. Magnetic concentration experiments with iron ores of the Bristol mines, Que.; iron ores of the Bathurst mines, New Brunswick; a copper nickel ore from Nairn, Ontario. By George C. Mackenzie, B.Sc. 28 pages, tables, 8vo., Ottawa, Government Printing Bureau, 1910.

First Universal Race Congress, University of London, July 26–29, 1911. Announcement, list of officers, programme of meetings. 16 pages, 12mo. London, Executive Committee. (n.d.)

Eighth International Congress of Applied Chemistry, Washington, 1912. Preliminary announcement. 31 pages, 8vo. New York. (n.d.)

The Broader Aspects of Research in Terrestrial Magnetism. By L. A. Bauer. Address of the retiring vice-president and chairman of Section B (physics), American Association, for the Advancement of Science, at the Minneapolis meeting, December 29, 1910. Reprinted from Science, N.S., vol. 33, No. 837 pp. 41–54, January 13, 1911. 30 pages, 8vo. Lancaster, Pa., 1911.

Carnegie Institution, Washington. Annual Report of the director, department of terrestrial magnetism, 1910. Reprinted from Yearbook No. 9, pages 195–204, plate 5. 10 pages, map, 8vo. Washington. (n.d.)

U. S. Department of Commerce and Labor. Bureau of the Census. Forest products, No. 7. Wood distillation, 1909. Compiled in coöperation with the Department of Agriculture, Forest Service. Henry S. Graves, forester. 11 pages, 8vo. Washington, Government Printing Office, 1911.

U. S. Department of Commerce and Labor, Bureau of the Census. Rice, cleaning and polishing. Preliminary comparative report for 1909. 7 pages, 8vo. Washington, Government Printing Office, 1911.

U. S. Department of Commerce and Labor. Bureau of the Census. Turpentine and rosin. Preliminary comparative report for 1909. 5 pages, 8vo. Washington, Government Printing Office, 1911.

Galvanostegie. I. Teil über elektrolytische metallniederschläge von Dr. Ing. M. Schlötter. 257 pages, illustrations. 8vo. Halle, a. S., Wilhelm Knapp, 1910. Price in paper, 12 marks.

CURRENT TOPICS

The Effect of Tarring Roads. MARCEL MIRANDE. (*Mon. Scientifique,* lxxiv, 66.)—The noxious influence of tarring on plants is due to the action of the disengaged gases and not to dust containing caustic elements. The tarring of embanked streets and avenues, such as are bounded by tall houses, can be very hurtful to trees planted on the sidewalks; the same thing can occur in open avenues with dense vegetation on the sides. Tarry dusts only act upon vegetation as *dust* if in sufficient quantity as to be a nuisance.

Electrolytic Preparation of Calcium. F. C. FRARY. (*Bull. Soc. d'Encour.,* cxiv, 459.)—In the electrolytic preparation of calcium it is necessary to use an artificially cooled cathode. The current density is only of importance in so far as it affects the temperature of the cathode. The chloride gives a better yield than a mixture of chloride and fluoride. Calcium is produced on a commercial scale by a Rathenan furnace at the Bitterfeld works. The electrolyte should be added continuously, and the cathode be raised regularly to remove the calcium.

Incandescent Lamps. G. RICHARD. (*Bull. Soc. d'Encour.,* cxiv, 500.)—The tungsten lamp has chiefly attracted the attention of electricians, on account of the recent improvements in making the filament more ductile and more resistant. At ordinary temperatures tungsten is exceedingly hard and brittle. It softens at the temperature of incandescence, but cannot be drawn into wire. To obtain wire-drawn filaments very pure tungsten is mixed with certain secret substances, which are afterwards volatilized. This leaves the metal ductile with a higher tenacity than steel. Analogous results have been obtained with molybdenum.

The Action of Air on Chloride of Lime. JULES GARÇON. (*Bull. Soc. d'Encour.,* cxiv, 454.)—Many researches have been made on the action of carbon dioxide and of air, on chloride of lime, or bleaching powder. When carbon dioxide reacts with it, either in powder or dissolved, chlorine only is given off. Air, deprived of all carbon dioxide, slowly liberates a little hypochlorous acid. Ordinary damp air acting on the powder, liberates at first a mixture of hypochlorous acid and of chlorine, then chlorine only. It has the same effect on the solution. Air, freed from carbon dioxide, sets free considerable quantities of chlorine from a solution of chloride of lime, containing no free lime.

To Prevent Dusting or Easy Abrasion of Improperly Laid Concrete Floors. ALBERT MOYER. (*Vulcanite Portland Cement Co.*)—Cement floors, particularly in office buildings or warehouses, which do not have the advantage of obtaining the necessary moisture from the atmosphere such as outside floors and sidewalks on which the dew falls at night, if not properly protected and kept damp, become prematurely dry and are therefore more or less porous and weak, causing easy abrasion under foot traffic, or what is commonly known as dusting.

Care should be exercised in keeping such floors damp by covering with wet sand, wet hay or straw, for a week or more until the floor has properly hardened. If this has not been done and the floors are found to dust under foot traffic, the following remedy will be found very easy to accomplish, economical and effective.

Wash the floor thoroughly with clean water, scrubbing with a stiff broom or scrubbing brush, removing all dirt and loose particles. Allow the surface to dry, as soon as dry apply a solution of one part water-glass (sodium silicate) of 40° Baume, and 3 to 4 parts of water, the proportion of water depending upon the porosity of the concrete. The denser the concrete the weaker the solution required. Stir well, and apply this mixture with a brush (a large whitewash brush with long handle will be found the most economical). Do not mix a greater quantity than you can use in an hour.

If this solution is sufficiently thin, it will penetrate the pores of the concrete. Allow the concrete surface thus treated to dry. As soon as dry, wash off with clean water using a mop. Again allow surface to dry and apply the solution as before. Allow to dry and again wash off with clean water, using a mop. As soon as the surface is again dry, apply the solution as before. If the third coat does not flush to the surface apply another coat as above.

The sodium silicate which remains on the surface, not having come in contact with the other alkalies in the concrete, is readily soluble in water and can therefore be easily washed off, thus evening up the color and texture of the floor. That which has penetrated into the pores, having come in contact with the other alkalies in the concrete, has formed into an insoluble and very hard material, hardening the surface, preventing dusting and adding materially to the wearing value of the floor.

Natural Gas in 1909 and 1910.—The production of natural gas in the United States in 1909, as ascertained by a joint canvass made by the United States Geological Survey and the Bureau of the Census, is estimated by B. Hill, in charge of this work, under the supervision of D. T. Day, to have been $55,000,000, an increase of only about $359,626 over that of 1908. There were no great changes in the industry during the year, the production continuing to decline in Kansas, and an increase being made in Oklahoma and

in the Caddo field in Louisiana and in Texas. An interesting feature was the supplying of Fort Worth and Dallas from the gas fields of Clay County, Tex. For the year 1910 the total production is estimated at $57,000,000, an increase of about $2,000,000 over 1909. During 1910 a feature of great interest was the development of what promises to be a very large supply of natural gas in the Buena Vista Hills, Kern County, Cal., east of the Sunset-McKittrick oil field. Arrangements were made and practically completed during the year for piping this gas to Bakersfield and other towns in San Joaquin Valley.

Reduction of Selenium or Tellurium. (*Eng. and Mining Jour.*, xc, 1091.)—The reduction of selenium or tellurium oxides to metal by carbon in the presence of soda or other bases is impossible, owing to the reaction between the base and the metalloid, resulting in the formation of selenides or tellurides.

A New Metal-Tempering Process. ANON. (*The Iron Age*, lxxxvi, 1318.)—P. J. A. Douglass, Dartmouth, N. S., has discovered a process for tempering non-ferrous metals. The special advantages claimed are non-corrosiveness, flexibility and a uniform temper. Metals thus treated will take a keen edge and are available for cutlery and all kinds of tools. It is possible to use castings of these metals which are cheaper than forged steel.

Dyeing, Tanning and Vulcanization. W. P. DREAFER. (*J Soc. Dyers and Col.*, xxvi, 268.)—The similarity between dyeing and tanning is pointed out, in that the solution phenomena are comparable and are closely concerned with the colloidal condition. The processes of absorption involved are paralleled in the case of vulcanization.

A New Pyrophoric Cerium and Magnesium Alloy. ANON. (*Brass World*, vi, 331.)—A. Huber of Berlin has produced a pyrophoric alloy by alloying 85 per cent. cerium with 15 per cent. magnesium. When this alloy is heated to a temperature of about 550° C. in a closed muffle furnace and hydrogen gas is passed in and absorbed by the metal, the pyrophoric qualities of the alloy are greatly increased.

A New Platinum Alloy. (*Iron Age*, lxxxvi, 783.)—W. C. Finck, a jeweler of Elizabeth, N. J. has patented a platinum alloy which can be used as a substitute for pure platinum for many purposes and only costs about 3 per cent. as much. It melts at a temperature 600° lower than platinum and does not corrode nor tarnish under the influence of the atmosphere or of acid fumes, but is slightly discolored by surphur. It is stated that it wears as

well as gold and is not distinguishable from platinum when alternated with gold in chains. It is used for diamond mounting and jewelry and it is believed will make good ignition points for spark-plugs and may be available for use in cauterizing instruments and wood-burning tools.

High-Tension Transmission Line Insulators. ANON. (*Electr. World,* lvi, 1127.)—The insulator acts as a condenser and must be designed so that the electric stresses in it are a minimum. When the capacity is large so also is the charging current which, spreading over the insulator, forms the corona, produces streamers, and gives rise to periodic flash-overs. The effect of rain is to increase the capacity of the insulator, and this tends to produce flashes to earth. The theory of these insulators is discussed and practical applications of it are given.

Solubility of Oxygen in Molten Silver. F. G. DONNAN AND T. W. A. SHAW. (*Soc. Chem. Ind. Jour.,* xxix, 987.)—The volume of oxygen absorbed by 10 Gm. of melted silver at 1020° C. and 751 mm. pressure was 20.5 c.c.; a second determination at 1020° C. and 753 mm. gave 20.2 c.c. These figures agree well with Sievert's, and show that the concentration of the oxygen in molten silver is proportional to the square root of the oxygen pressure over a wide range of pressures. From this it is concluded that the oxygen is either physically dissolved as atomic oxygen, or exists in the form of dissolved silver monoxide.

The Effect of Carbon and Carbon Monoxide in Metallurgical Reactions. G. CHARPY. (*Rev. Met.,* vii, 962.)—In studying the effect of pure carbon at high temperatures on iron and allied metals, it is very difficult to eliminate all occluded gases. With the oxides of these metals the temperature of their dissociation affects the results considerably. It is, however, concluded that up to a temperature of 1000° C., pure carbon has no action on the metals of the iron family, or their oxides; that carbon monoxide at the same temperatures carburizes iron, reduces all the oxides of iron and nickel and the higher oxides of manganese, oxidizes metallic chromium and manganese, and has no appreciable action on metallic nickel, manganous oxide and chromium tri-oxide.

A New Vegetable Wax Found in Mexico. ANON. (*Revue Scientifique,* xlviii, 842.)—In the district of North Mexico, where the caoutchouc plant "Guayule" is found, there grows a little plant which the natives call the "candelilla" or little candle, on account of its shape. The whole of the plant except its roots is covered with a wax, which in the United States has been considered as beeswax and has been recognized as superior to car-

nauber wax. Samples of the candelilla wax were sent to a London firm who immediately purchased 50 tons a month of it. The candelilla is found in the southern regions of Mexico, but in an insufficient quantity for commercial purposes. It easily reproduces itself and requires little care. When cut down level with the soil it grows again in one or two years, and is very prolific.

Aluminum-Bronze Coinage. ANON. (*Revue Scientifique,* xlviii, 844.)—The French Coinage Commission reported against an aluminum coinage, as neither aluminum nor its alloys offer sufficient resistance to blows and friction. They recommend aluminum-bronze, an alloy of 90 per cent. copper and 10 per cent. aluminum. The coins have the beautiful yellow color of gold and to prevent any confusion the Committee recommend that the coins be pierced with a central circular orifice, which would be a sufficient guarantee against their being mistaken for gold coins.

Structure of Graphitic Cast-Iron. OTTO KRÖHNKE. (*Metallurgie,* vii, 674.)—When cast-iron is transformed into the graphitic condition by corrosion, the ferrite is removed from the pearlite, while cementite and iron phosphide remain unchanged. The graphite retains its position in the mass, but is partly converted into a white or gray substance, graphitite, of unknown composition. White cast-iron does not undergo such a change, as the constituents resist corrosion. Wrought-iron, although containing small quantities of pearlite, does not corrode in this way, the presence of graphite being necessary to produce the requisite electrolytic couples.

Radium Lode in South Australia. D. MAWSON. (*Pharm. Jour.,* lxxxv, 804.)—Radio-active mineral is found at Yudna Mutana, containing carnotite and torbernite, which is a hydrated uranium copper phosphate and this occurrence is unique in Australasia.

Fertilizer Value of Manganese Sulphate. A. CARLIER. (*Biedermann's Zentr.,* xxxix, 859.)—Manganese sulphate was added in the proportion of 44.5 pounds and 89 pounds per acre to grass land. In the first case there was an increase of 0.9 per cent. and in the second of 9.5 per cent. in the hay crop. A few days after the addition of the fertilizer its action became evident as the plot appeared a vivid green. In the case of potatoes and turnips, the crop actually diminished; the potatoes lost 9 per cent. in the first case and in the second, lost 0.6 per cent., with turnips the roots showed 2.5 and 1.0 per cent. respectively less, and the leaves 25 per cent. and 20 per cent. respectively less. These results show that manganese sulphate does not possess the high fertilizer value often attributed to it.

Making Auto Motors and Parts. E. F. LAKE. (*Amer. Mach.*, xxxiv, 95.)—This article gives some methods and machines employed in machining the engine cylinders, piston rods and small levers. Testing and balancing the fly-wheels. The means employed to test the assembled motors, transmissions, rear axles and springs of an automobile. To those interested this article will be found valuable.

Fire Engine Work. F. A. STANLEY. (*Amer. Mach.*, xxxiv, 112.)—This article will repay careful perusal by those interested. It refers to the construction and application of a drill-press device for chucking work of irregular outline for drilling and tapping. They are presented either side up to the tools and can be set easily in any position under the spindle. Some boring, facing, and tapping tools for mounting directly on the end of the spindle are described.

Color Screens on Celluloid Films or Coatings. (Eng. Patent of C. SPAETH, 23,138, Oct. 6, 1910.)—In the preparation of color screens by successively staining portions of a celluloid surface with solutions of different dyestuffs, it is proposed to dilute the solvent used for making the solution more and more for each successive staining; as in this way the previously stained surfaces are not affected by the more dilute solutions. A celluloid film may be coated on each side with a thin layer of rubber and on one of these layers a series of lines is scratched to expose the celluloid surface; the film is now dipped in a solution of 2 Gm. of Victoria Blue in 100 c.c. of absolute alcohol, washed and dried; a second series of lines is scratched on the surface, preferably perpendicular to the first, and the film immersed in a solution of 2 Gm. of Auramine and 1 Gm. of Ethyl Green in 150 c.c. of 80 per cent. alcohol, washed and dried. The remaining rubber coating is washed off the one side of the celluloid, and the film is immersed in a solution of 2 Gm. of Rubin and 1 Gm. of Auramine in 150 c.c. of 60 per cent. alcohol. The resulting screen will consist of blue lines and green and red squares.

Constitution of Troostite. A. MCCANCE. (*Engineering*, xc, 905.)—"Troostite" is the micrographic constituent of steels discovered and described by Osmond. Microphotographs of steels show that the carbon content of troostite may vary, and that it should not be considered as finely divided pearlite, although being a transition product, it is a stage in the development of pearlite in the same sense as martensite is, and pearlite may be obtained ultimately from both martensite and troostite. From a discussion of the curves given for the expansion of a bar of steel, for the residual magnetism, for the changes in magnetic intensity on reheating, and for the variation in density on tempering, it is concluded that troostite is amorphous and uncrystallized α-iron which has not

yet attained its crystalline state of ferrite. On re-heating a quenched steel, the first effect is to change the iron to the uncrystallized α-form (troostite) from which the carbon (since it is insoluble in α-iron) is deposited *in situ* as $(Fe_3C)_2$. This is unable to polymerize into $(Fe_3C)_4$ (cementite) and remains in suspension; hence it is concluded that troostite contains carbon in suspension and not in solution. Above 450° C. the α-iron crystallizes as ferrite in low carbon steels, and with increasing polymerization of the carbon compound, the remaining complex mass becomes sorbitic and finally pearlite.

Action of Radium Rays on Colloids. W. P. JORISSEN AND H. W. WONDSTRA. (*Zeit. Chem. Ind. Kolloide,* viii, 8.)—On exposing a ferric oxide solution prepared by digesting ferric oxide with ferric chloride solution and subsequent dialysis, to the radiation from radium bromide contained in thin glass tubes, the authors were able to confirm the statement of Henri and Mayer, that the ferric oxide solution in presence of a quantity of sodium nitrate insufficient alone to cause coagulation, is coagulated when exposed to the radium preparation. Although the ferric oxide solution alone apparently remains unaffected by exposure to the radium bromide, it is in fact rendered more sensitive, for generally it is coagulated by quantities of electrolytes insufficient to cause coagulation of a similar solution which has not been so exposed. The radium rays have no observable similar effect on a silver solution.

Cause of Efflorescences on Mortars and Stones. P. ROHLAND. (*Z. Chem. Ind. Kol.,* viii, 48.)—Efflorescences on mortars, bricks, etc., are caused by crystalloid substances (acids, bases or salts) and not by colloids. The extent of the efflorescence depends partly on the porosity of the mortar, bricks, etc., for in a very porous material the soluble salts may crystallize partly in the interior of the material, whereas with a material of close structure the water, with its dissolved salts, is forced to the surface. Soluble salts may separate quantitatively on the surface of mortar, etc., after hardening. For example, if plaster of Paris be guaged with water containing 0.05 Gm. of copper sulphate in solution, the plaster remains pure white during setting and hardening, but after several hours, the blue copper sulphate crystallizes out on the surface quantitatively.

Influence of Soluble Sulphates on Kaolins and Clays. R. RIEKE. (*Sprechsaal,* xliii, 709, etc.)—The soda-slip casting process has now attained such recognition that the rival theories of plasticity,—one attributing it to the presence of colloids, the other to soluble salts in the clay,—become of commercial importance. The influence of soluble sulphates on the fluidity of slip, and their adsorption by clay, have therefore been examined, and the following

conclusions reached. Most soluble sulphates increase the viscosity of a slip, and therefore barium hydroxide should be added to the slip. The most harmful sulphates are those of calcium, aluminum and the heavy metals. Alkali sulphates stiffen the slip up to 0.1 per cent., then render it more fluid up to 1.0 per cent., and then stiffen it again. Zinc and copper sulphates act in the same way. The curve representing the activity of the salts rises rapidly on small additions of sulphates, but slower on large additions. It is also dependant to some extent on the proportion of clay to water in the slip. Water free from sulphates should be used. Clays absorb sulphates in small quantities, though sometimes the clay absorbs the metallic iron, leaving the sulphate iron to withdraw an alkali metal from the clay, by double decomposition.

Electric Furnaces in Non-Ferrous Metallurgy. J. W. RICHARDS. (*Met. Chem. Eng.*, viii, 233.)—The advantages of electric-over blast-furnaces are: They produce purer metal castings and crucible quality alloys, due to the absence of injurious gases. They are efficient for roasting sulphide and arsenide ores, as there is no interference with oxidation. The process of concentrating ores to mats can be better regulated. They are especially valuable for reducing to metal, as there will be less volatilization and fume loss, owing to the smaller volume of combustion gases; moreover a uniform temperature can be maintained throughout and only as high as may be necessary. For roasting ores so as to condense the metallic vapors, zinc for example, heat may be supplied inside the retorts instead of outside, thus increasing the calorific efficiency.

The Constituents of the Active Deposit of Actinium. L. BLANQUIES. (*Comptes rendus*, cli, 57.)—Experiments conducted to prove or disprove the existence of a substance giving rise to Act B. and emitting α rays, did not give irrefutable proof, but: (1) The assumption that this substance exists furnishes a simple explanation of the peculiar form of Bragg's ionization curve for the induced activity of Actinium. (2) The assumption accounts for the difference in the law of disappearance of the scintillations for polonium as compared with that of the active deposit of actinium. (3) The initial drop in the decay curve supports the above hypothesis. (4) The hypothesis explains the observation of Geiger and Marsden that 10 per cent. of the scintillations produced by the active deposit of actinium are double.

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